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THE UNIVERSITY OF ALBERTA

Structure and stratigraphy of the coal-bearing and adjacent
strata near Cadomin, Alberta

by



Kevin C. Hill

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

IN

Department of Geology

EDMONTON, ALBERTA

Spring 1980

THE UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Structure and stratigraphy of the coal-bearing and adjacent strata near Cadomin, Alberta submitted by Kevin C. Hill in partial fulfilment of the requirements for the degree of Master of Science in Structural Geology.

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ABSTRACT

In a 100 sq km area of highly deformed, Jurassic-Cretaceous, 'clastic- wedge' strata near Cadomin, Alberta over 1100 outcrops were examined and data from more than 2500 boreholes were analyzed. Existing numerical computer-based techniques were used to store, retrieve and process the data. The area was divided into 45 domains within which folding can be considered cylindrical; down-plunge projection and rotation of these domains facilitated generation of profiles, cross-sections, maps and a composite section. Existing programs were modified and new programs developed to analyze the large quantity of borehole data.

The strata beneath the Nikanassin Thrust, which bounds the area to the southwest, range from the Jurassic Fernie Group to the Upper Cretaceous Wapiabi Formation. A composite lithologic section through the coal-bearing Luscar Formation and basal Mountain Park Formation was drawn up and interpreted with respect to palaeo-environment. The Luscar Formation was divided into 4 members which were correlated with the divisions of previous workers in the central Albertan Foothills. The members are: (A) 126 m of coarsening upward, thinly interbedded sandstones, siltstones, shales and thin coal seams interpreted as the infills of interdistributary bays on a fluvial dominated delta top; (B) 95 m of marine shale as a regressive sequence following a marine transgression, the marine shales correlating with the Moosebar Formation of northeast British Columbia; (C) 43 m

of thick, resistant, massive sandstone which may represent a beach or barrier sand; (D) 182 m of thick, fining upward, non-marine sandstones and siltstones together with both thick and thin coal seams interpreted as channel deposits on a broad alluvial flood plain, comparable to the interior modern Niger Delta.

Regionally, the structure comprises the southeasterly plunging Luscar anticlinorium in the northeast and adjacent Cadomin synclinorium in the southwest. In the tightly folded Lower Cretaceous strata the limb connecting anticlinorium to synclinorium has been cut at a high angle by the Luscar Thrust. In the hanging wall of the thrust the Mountain Park Formation exhibits round concentric folds whilst the 'Moosebar' shales in the cores shows tight to isoclinal chevron folds. The Upper Cretaceous Cardium Formation is more openly and gently folded and has been cut by at least 3 major thrust-faults, one of which has been folded such that it dips down to the northeast. The intervening Blackstone Formation is highly folded and faulted, comprising a zone of disharmony between the differing styles of deformation above and below.

A through-going detachment is inferred in the Blackstone Formation, of approximately 15 km displacement, the thrust faults cutting the Cardium being interpreted as early formed splays from this detachment. Gravity sliding of the Lower Cretaceous strata along a 'Moosebar' shale detachment on the northeast dipping limb of the ancestral

Nikanassin Range anticline preceded and initiated displacement along the Luscar Thrust. A later folding event caused the Luscar Anticlinorium to develop, folding the overlying thrust-faults in the process.

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1. INTRODUCTION

Cretaceous and Palaeocene coal are known to occur along the entire length of the Rocky Mountains in Alberta and British Columbia. Although this coal will supply much of Western Canada's future energy needs, little has been published on the detailed structure of the coal-bearing and adjacent strata. The main purpose of this study was to determine and interpret the structure of the highly deformed coal-bearing and adjacent Jurassic-Cretaceous strata in a 100 sq km area near Cadomin, Alberta. Ancillary objectives were (1) to produce a detailed geological map and cross-section of the area, (2) to construct a detailed stratigraphic section of the Luscar Formation, (3) to develop computer techniques for analyzing large quantities of borehole data and to refine existing techniques for treating outcrop data and (4) to relate the structure of the Luscar Formation to that of the underlying and particularly that of the overlying beds.

Cadomin itself is situated in the Foothills of west-central Alberta, approximately 50 km south of Hinton and 320 km west of Edmonton. Situated between the Nikanassin Range to the southwest and the Lookout Ridge to the northeast much of the area studied lies between the transverse valleys of the McLeod and Gregg Rivers (fig 1).

Relief is pronounced, particularly in the southwest where the Nikanassin Range is incised by the McLeod River. Elevations range from 1500 m (4900 ft) along the McLeod River to over 2500 m (8200 ft) in the Nikanassin Range.

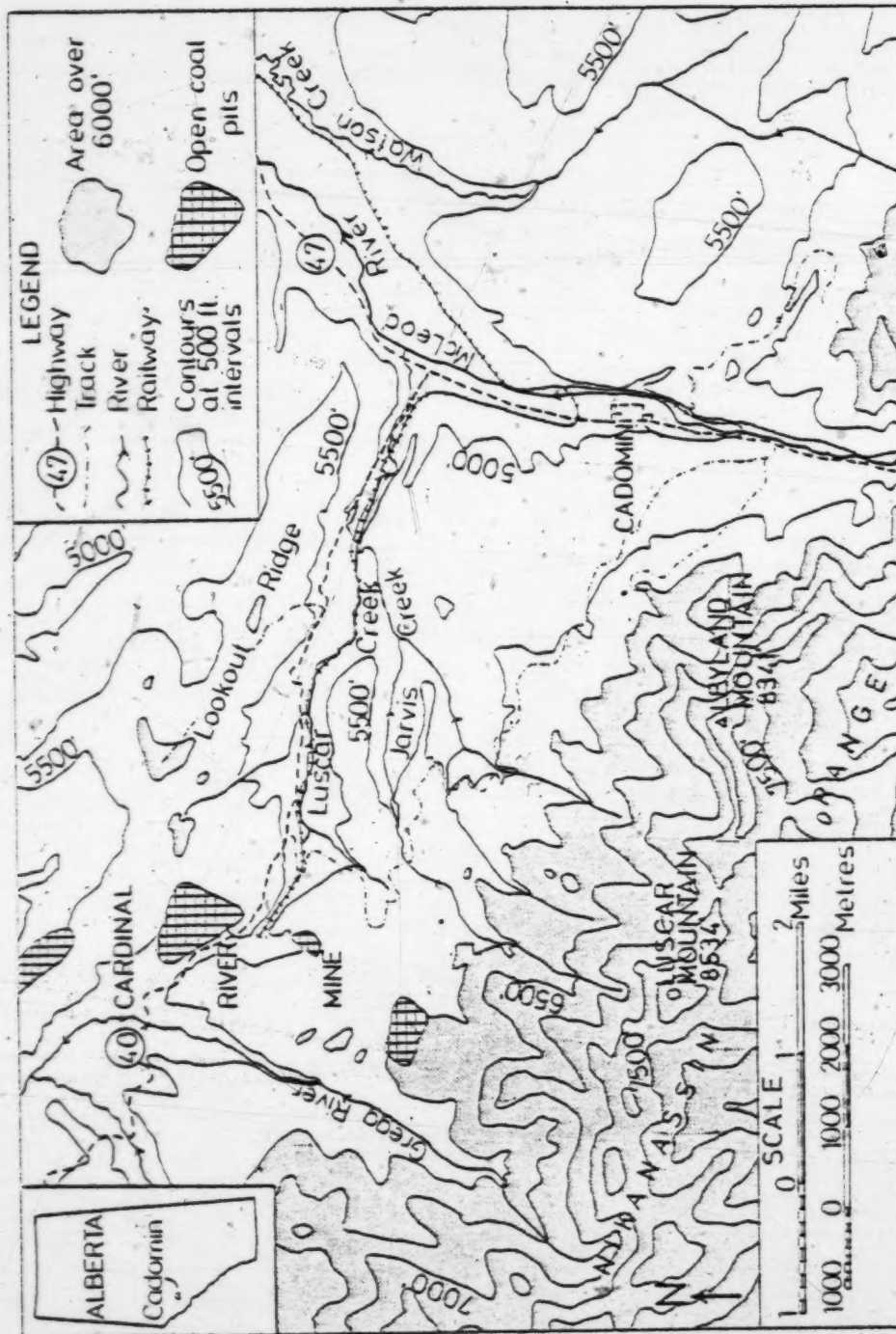


Figure 1: Location and physiographic features of the Cadomin area.

Vegetation is largely controlled by elevation with spruce, pine and poplar on the lower slopes passing up into sub-alpine vegetation and ultimately alpine tundra, but with alders and willows along the rivers and streams of the lowlands (Halladay, 1966).

The best natural exposures are found on the unforested high ground in the southwest, along the McLeod River and on the Lookout Ridge. The most complete exposure is found in the open coal pits of the Cardinal River Mine (plates Ib and III) and in the line of underground-mine cavings along the lower slopes of the Nikanassin Range (plate Ia). Access is facilitated by Highway 40 from Hinton, Highway 47 from Edson and the C.N.R. "Coal branch" line from near Edson with spurs to the Cardinal River Mine and to the Inland Cement Quarry. There are also numerous mine roads, both old and new, usually accessible only to a 4-wheel drive vehicle or trail bike.

The existence of the Jewel Seam, which averages 12 m (40 ft) in thickness, has been known since the turn of the century and it has been mined on several occasions. John Gregg staked a claim at Luscar in 1911 and a mine was developed there by Luscar Coals Ltd. in 1921. The seam at Cadomin was discovered by Frederick L. Hammond in 1912 and developed by the Cadomin Coal Company Ltd. in 1917 (Ross, 1974). In 1920 the rock tunnel system was introduced at Cadomin whereby the steeply dipping coal seam was mined upwards from a horizontal adit. This gave rise to the line

of cavings along the lower slopes of the Nikanassin Range. Diminishing markets and production difficulties led to closure of the Cadomin Mine in 1952 and the Luscar Mine followed suit in 1956.

The Cardinal River Mine was opened in 1970 with the mine plant being built on the site of the now deserted Luscar township. This was brought about by the advent of a new market, namely the Japanese steel industry. The mine has recently expanded and is now producing 2.7 million short tons of clean coal per annum from its 3 operating pits. Proven reserves are 28 million clean short tons and inferred reserves are 107 million clean short tons. The coal is of high-volatile, bituminous rank in the southwest, but of medium-volatile bituminous rank in the northeast. Cardinal River Coals Ltd. operates an extensive exploration program which has supplied much of the data for this study.

The Cadomin area was mapped by the Geological Survey of Canada in the late 1920's (MacKay 1929) and referred to in reports by MacKay (1928, 1930). The Edmonton Geological Society has published a field guide to the area (Williams, 1966). Kryzcka (1959) studied the Nikanassin Formation around Cadomin and McLean referred to the Cadomin area in his papers on the Cadomin conglomerate (McLean, 1977) and on Lower Cretaceous nomenclature (McLean, in press). Many authors have referenced the Cadomin area in regional studies including Mellon and Wall (1963), Mellon (1967), Stott (1974) and Schultheis and Mountjoy (1978).

II. DATA COLLECTION, STORAGE AND PROCESSING

A. Outcrop Data

Four months were spent in the field during the summers of 1978 and 1979. Most of the time was spent collecting positional, structural and stratigraphic data from outcrops, although some of the second summer was devoted to measuring stratigraphic sections. As many outcrop data as possible were recorded on field data sheets similar to those used by Wrightson (1979, p. 7) and whose format is described in Appendix 1a. Information on lithology, faults, joints etc. together with general observations were recorded in conventional field note books.

In the field the positions of outcrops were marked on aerial photographs by means of small pinpricks with outcrop numbers on the back. Two sets of photographs were available, both prepared by Western Photogrammetry Ltd. The first was taken in 1977 and encompassed the whole area on a scale of 1:19200, whilst the second set, updated monthly, covered the area of the mine operation on a scale of 1:9600. Enlargements of the former set at a scale of 1:9600 were used for field mapping.

In the evenings the outcrop locations were transferred to base-maps, again available on two scales. The first set covered most of the area on a scale of 1:4800 with a contour interval of 10 ft (3 m) and in some places 25 ft (7.6 m) and the second set covered the mine pits on a scale of 1:1200

with a 5 ft (1.5 m) contour interval. The area to the east of the McLeod River had not been mapped on this scale so Western Photogrammetry Ltd. were contracted to produce a base-map on a scale of 1:4800. The co-ordinates, easting, northing and elevation, of outcrops were measured from the maps and entered on the field data sheets.

The main sources of location error are:- i) location on the photograph, ii) transfer of location to the map, iii) measurement of co-ordinates on the map and iv) inaccuracies of the map. Of these only the first two are considered significant and the error is thought to be less than 3 m (10 ft) for the vast majority of outcrops. The grid lines on the 1:4800 maps were spaced 2.5 in (6.3 cm) apart, corresponding to 1000 ft (305 m) on the ground, so horizontal co-ordinates could be measured to within 5 ft (1.5 m); contour intervals being either 5, 10 or 25 ft (1.5, 3 or 7.6 m) meant that elevation measurement could be at least as accurate.

In 1978 an interactive computer terminal was available in the field so that data could be entered into the computer weekly. This saved a great deal of time after the field season and facilitated production of outcrop maps to check for location errors and construct field maps. Although expensive, the cost could be reduced by the use of a teletype terminal whereby all the data may be entered before linking into the computer, thus minimizing the long distance telephone charges.

Data from 1136 outcrops were recorded, 1092 being

readings of planar bedding, the remaining 44 being mesoscopic fold readings. At each planar outcrop up to 6 readings of dip direction and dip were measured within a few metres of one another, using a Freiberg structural compass calibrated in grads. Repeated measurements were taken, firstly to obtain a better estimate of the true reading and, secondly, to enable statistical tests to be carried out. At outcrops displaying mesoscopic folds 6 or more representative readings of bedding orientation were taken in order to calculate the fold axis.

Data recorded on field data sheets from "planar" and "folded" outcrops were entered into line files RAWPLANE and RAWFOLD, respectively, each line in the file corresponding to one sheet and columns in a file corresponding to spaces on the sheet (appendix 1b). Using programs developed by Wrightson (1979, pp. 11-14) (appendix 7), data in the file RAWPLANE were reformatted and processed to calculate, for each outcrop, a mean orientation in degrees and a statistical parameter estimating the scatter of the repeated measurements. The output file PLANE (appendix 1c) is formatted such that it can be used as input to the existing plotting, rotating and projecting programs (Wrightson, 1979, pp. 14 and 18-20). Data in RAWFOLD were processed by the source programs FINPUT and EIGEN (available in the Department of Geology) to give a mean local fold axis orientation for each outcrop. Each set of bedding orientations was converted to degrees and placed in a

temporary file to be used as input to FINPUT and EIGEN. The resulting values were placed in a file FOLD (appendix 1d) with a format acceptable to the map plotting program DRAW (Wrightson, 1979, p. 14) and a map of the local fold axes was produced (fig 2).

B. Borehole Data

Cardinal River Coals Ltd. is carrying out an extensive exploration program which to date has included the drilling of more than 2500 boreholes. The boreholes are located using the mine property survey system comprising 5 northwesterly trending baselines and 18 northeasterly trending section lines which are 3000 ft (914 m) apart and normal to the baselines (fig 3). Discrepancies in the initial surveying of the baselines has resulted in them not being exactly parallel and eastings and northings of 6 reference points as well as bearings are used to define them (appendix 2a). The mine pits are also referenced using this survey system.

The majority of boreholes were logged and the data recorded on summary sheets made available to the author (fig 4). The first 3 columns record the hole number, its azimuth (trend) and inclination (plunge), most of the holes being vertical. The remaining columns on the data sheet are self explanatory, though it should be noted that electric logs were not always run and that data were not always complete (appendix 2b). Incomplete data sets were omitted. A 'J' or an 'R' was recorded in the column labelled 'No.' if the seam

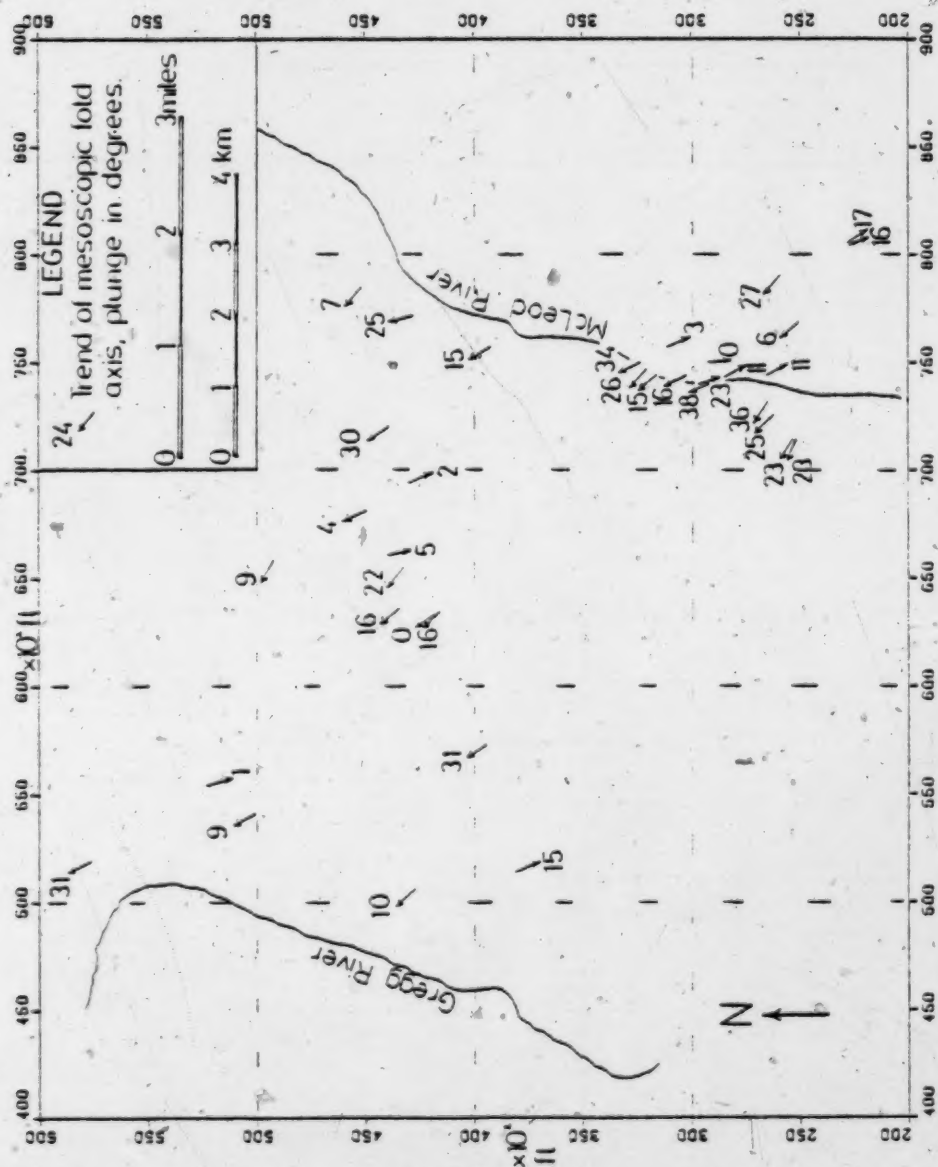


Figure 2: Orientations of mesoscopic fold axes.

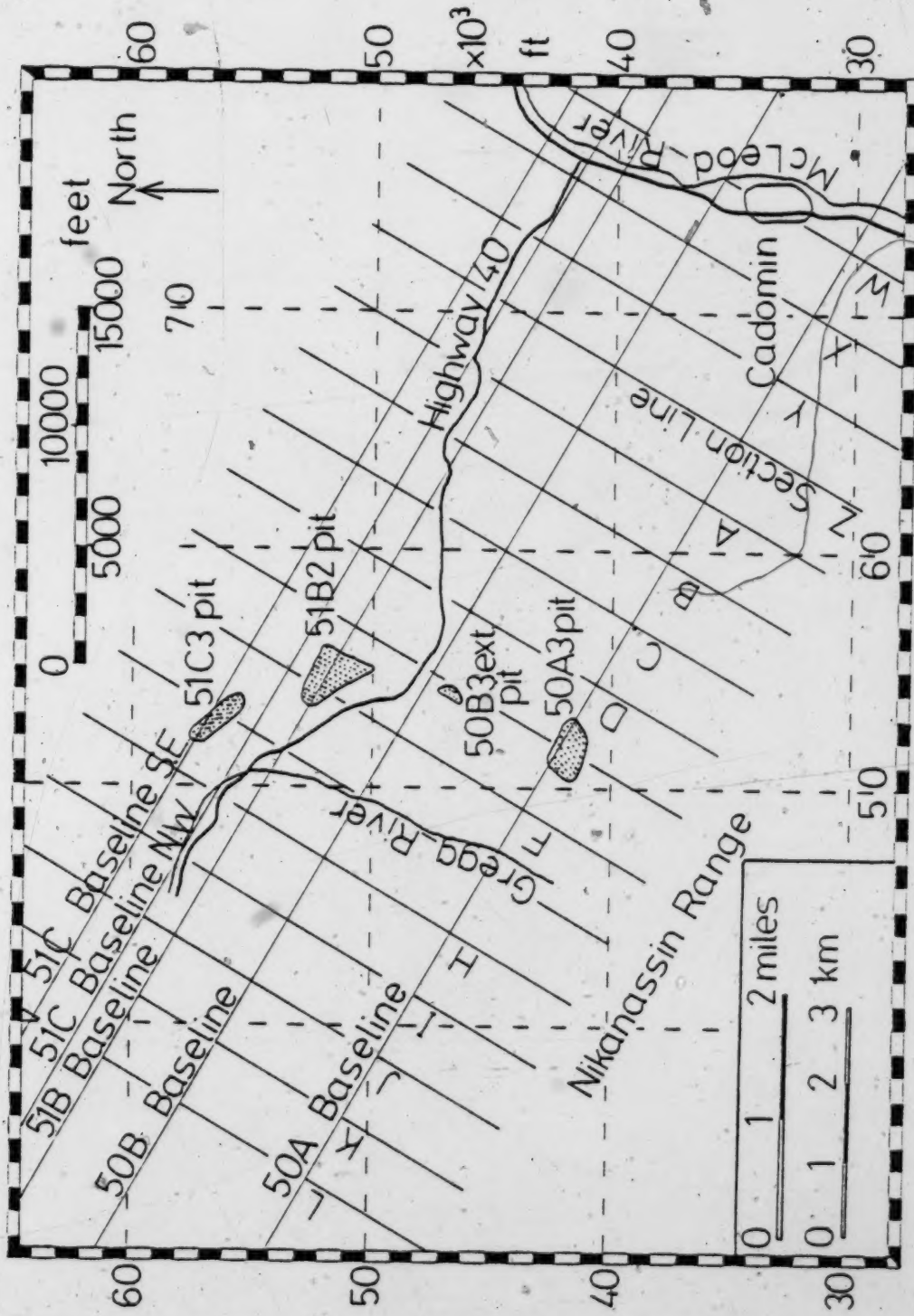


Figure 3: Mine survey system and the reference grid, in feet.

was known to be Jewel or Ryder Seam respectively.

The summary sheets were used to build 3 computer line files. The file HOLE (appendix 2c) contains data defining the positions and orientations of the holes. Each line in the file SEAM (appendix 2d) contains downhole depths to the tops and bottoms of coal intervals, one line per interval. The file COMMENT (appendix 2e) contains any comments recorded for each hole. The files are cross-referenced by hole number. Thus while each borehole has a one line entry in the file HOLE, the number of lines it has in SEAM depends on the number of coal intervals and only boreholes with comments in the summary sheets have entries in the file COMMENT.

The borehole co-ordinates in SEAM and HOLE were converted to eastings, northings and elevations using the program CONVERT (appendix 3a). This program comprises 2 parts. The first part uses simple trigonometry to change the collar co-ordinates of each borehole to easting, northing and elevation placing the new co-ordinates and the hole number in a file COLLARS. The second part calculates the co-ordinates of every intersection of the borehole with the top or bottom of a coal interval using the collar co-ordinates, azimuth and inclination of the borehole from HOLE and the downhole depths from SEAM. The output data were placed in the file CARDINAL and comprise hole number, co-ordinates of the intersection and seam identity if known. The formats of files COLLARS and CARDINAL are given in

appendix 3g.

The file COLLARS was processed by the program ADJUST (appendix 3e) which rearranged the data so as to be acceptable to the map plotting program DRAW and added 2000 to the hole numbers so that they did not clash with any of the outcrop numbers in PLANE. The output file COLLAR1, was used as input to DRAW to produce a map of borehole collars.

Since the boreholes penetrated up to 14 coal intervals and since each interval generated 2 lines in the file CARDINAL the latter contained over 12000 lines, most of which were irrelevant to this study. The data required were the co-ordinates of the top and bottom of the Jewel Seam where it was present and where absent, the top and bottom of the hole. Some intervals were labelled as belonging to the Jewel or Ryder Seams. However, most were unlabelled even though they were in fact intervals of the Jewel Seam separated by shale partings.

To distinguish the Jewel Seam from others, the author used a minimum downhole thickness of 6 m (20 ft) for a single coal interval. This cut off is justified by the following:-

- 1) The Jewel Seam was measured to be 12 m (40 ft) thick in the limbs of folds and thicker in the cores whereas all other seams, excluding the Ryder Seam, are less than 1 m (3 ft) thick.
- 2) The Ryder Seam is 3.7 m (12 ft) thick and would have an apparent thickness of more than 6 m only if it made an angle

of less than 37° with the borehole. Also, the Ryder Seam has marked shale partings so that it is rare for any coal interval to exceed 6 m in downhole thickness.

3) The inclined boreholes are almost always drilled perpendicular to bedding so that true thickness is recorded.

4) Often only the top and bottom of the Jewel Seam are recorded so that the thickness greatly exceeds 6 m.

5) A few intersections with the Jewel Seam are inevitably missed where all the internal partings are recorded.

However, in the pits drilling density is very high and one or two boreholes will be of no consequence, whilst in areas where holes are few and far between each hole may be checked individually.

6) Once the seams were plotted on profiles it was easy to identify those that were incorrectly labelled.

Therefore, the file SEAM was processed by the program SMED (appendix 3f) to output SEAM2 containing only the 1700 holes either known to intersect Jewel Seam or with at least one coal interval exceeding 6 m in downhole thickness (appendix 7). Furthermore, SEAM2 contained only the highest 6 m thick coal interval for each hole and the top of this was taken to mark the top of the Jewel Seam.

The program CONVERT was rerun with SEAM2 and HOLE as input and CARDINAL2 as output. CARDINAL2 contained co-ordinates of both top and bottom of the highest coal interval greater than 6 m thick. It was edited by the program CAR2DIT (appendix 3b) to add 2000 to each hole

number and retain only the top co-ordinates, the output being placed in the file JEWEL2. A similar procedure was used to obtain JEWEL3 from SEAM3, which contained only the lowest coal interval greater than 6 m thick, the bottom of which was taken to mark the base of the Jewel Seam.

In each of the 700 boreholes without a coal interval thicker than 6 m, the Jewel Seam was assumed to be missing from the stratigraphic section between the top and bottom of the hole. The program FIND (appendix 3c) uses JEWEL2 and HOLE as input and places those holes assumed not to intersect the Jewel Seam in the output file HOLES, adding 2000 to the hole number. The program CON (appendix 3d) uses HOLES as input placing the co-ordinates of the top and bottom of each hole assumed not to intersect the Jewel Seam in the output files NOCOAL and NOCOALB respectively. These data were labelled with a '5' to distinguish them from the Jewel Seam, labelled with a '1' and the Ryder Seam labelled with a '2'.

C. Mine Workings Data

Data from the old mine workings were made available to the author and 20 sets of co-ordinates of the Jewel Seam were added to the data in JEWEL2. These data were labelled with a '4' to distinguish them from the above.

D. Summary of Data

Data from outcrops, boreholes and mine workings were processed to give the files PLANE, JEWEL2, JEWEL3, NOCOAL and NOCOALB, all of which have the same format. This format is acceptable as input to the programs previously written for processing structural data, available in the Department of Geology. Any of the last 4 files may be added to PLANE as artificial outcrops which are then treated as outcrops lacking orientation data.

E. Establishing Domains

The numerical computer based techniques used for structural analysis depend upon folding being cylindrical. Obviously this is not the case throughout a 100 sq km area of highly deformed rocks. Therefore, the area was divided into 45 domains, each of which could be considered cylindrical.

The method for establishing cylindrical domains in areas with abundant outcrop data is well explained by Wrightson (1979, pp 15-18) and is only summarized here. Areas in which the folds are judged by inspection to be cylindrical are delineated and the relevant outcrop lines from the file PLANE are placed in separate files. For each potential domain a parameter known as the standard scattering angle, the maximum, intermediate and minimum eigenvalues and associated eigenvectors of a 3x3 matrix of summed direction cosines of outcrop bedding-poles and a

statistic used in a test of cylindricity are calculated. Anomalous outcrops are rejected. The potential domain is then divided into 2 halves in order to calculate firstly, a statistic for an F test of cylindricity and secondly, the orientation of the fold axis in each half, given by the eigenvector associated with the minimum eigenvalue.

The author's limits on the above parameters for acceptance of cylindricity differ from those of Wrightson in that the maximum acceptable values for both the standard scattering angle and for the angle between the fold axes of the 2 segments are considerably higher. Moreover, in certain cases not all the criteria were satisfied. The more highly deformed nature of the folding in the area necessitated this. The criteria used for accepting cylindricity were (cf Wrightson, 1979, pp 17-18):-

- 1) The intermediate eigenvalue was less than an order of magnitude smaller than the maximum eigenvalue, and more than an order of magnitude greater than the minimum eigenvalue.
- 2) The standard scattering angle was less than 10° .
- 3) The angle between the fold axes of separate segments of a domain was less than 10° .
- 4) The null hypothesis of cylindricity associated with the F test could not be rejected even if that associated with Chi-squared test was rejected.

In practise the 2 halves of the domain were established using the program SELECT (Wrightson, 1979, p. 74) and placed in the temporary files -D1 and -D2. The source program


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1 COPY -D1(1, LAST-1) -CD
2 COPY -D2(2, LAST) -CD(LAST+1)
3 R HAKC:CYLTEST+PLOTLIB 1--D1 2--DUMMY* 5--DUMMY* 6--D4 8--DUMMY* 9--DUMMY* T=2
4 R FTEST 1--D4 2--D6(LAST+1) 3--D7(LAST+1) T=2
5 EM -D4
6 R HAKC:CYLTEST+PLOTLIB 1--D2 2--DUMMY* 5--DUMMY* 6--D4 8--DUMMY* 9--DUMMY* T=2
7 R FTEST 1--D4 2--D6(LAST+1) 3--D7(LAST+1) T=2
8 EM -D4
9 R HAKC:CYLTEST+PLOTLIB 1--CD 2--DUMMY* 5--DUMMY* 6--D4 8--D5 9--DUMMY* T=2
10 R FTEST 1--D4 2--D6(LAST+1) 3--D7(LAST+1) T=2
11 C -D5 -D7(LAST+1)
12 EM -D4
13 EM -D5
14 R CALC 1--D6 2--D7(LAST+1) T=2
15 R XTEST 5--CD 6--D8 T=2
16 R MOVE 1--CD 2--CDC T=1
17 C SLASH(1,1) -CDC(LAST)
18 R HAKC:CYLTEST+PLOTLIB 1--CDC 2--DUMMY* 5--DUMMY* 6--D4 8--DUMMY* 9--DUMMY* T=2
19 R CALCX 1--D4(9,9) 2--D8(3,3) 3--D7(LAST+1) T=1
20 EM -D4
21 EM -D8
22 EM -D6
23 EM -D1
24 EM -D2
25 EM -CDC

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Figure 5 : Source program STATEST, incorporating the programs CYLTEST, FTEST, CALC, XTEST, MOVE and CALCX.


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9 STATIONS

TREND	PLUNGE	EVAL	EVAL/N
19.6116	73.8890	5.4946	0.6105
211.0009	15.8097	3.4826	0.3870
120.1443	3.0224	0.0228	0.0025

STANDARD DEVIATION= 0.057045

11 STATIONS

TREND	PLUNGE	EVAL	EVAL/N
207.0777	41.0321	8.3271	0.7570
23.7854	48.9211	2.6503	0.2409
115.6576	1.6313	0.0226	0.0021

STANDARD DEVIATION= 0.050166

20 STATIONS

TREND	PLUNGE	EVAL	EVAL/N
209.4164	50.7460	12.2901	0.6145
25.3159	39.1985	7.6489	0.3824
117.2556	1.7647	0.0609	0.0030

STANDARD DEVIATION= 0.058173

100MS 0

SD FROM EIGENVALUE= 0.058173 SD COMPUTED= 0.058173

NO.	X	Y	DEV	SD
1	80370.	26080.	-0.040676	0
2	80520.	25970.	-0.039785	0
3	80680.	25820.	-0.013172	0
4	80750.	25620.	-0.012458	0
5	81180.	25960.	0.086150	1
6	80840.	26210.	-0.071207	1
7	80640.	26270.	0.103048	1
8	80760.	26120.	-0.059701	1
9	80450.	25780.	0.055495	0
10	80800.	27140.	0.003661	0
11	80450.	27290.	-0.070548	1
12	79770.	26530.	0.064519	1
13	80080.	26370.	-0.052561	0
14	80320.	26560.	-0.020263	0
15	80080.	26580.	0.072516	1
16	79920.	26650.	0.081457	1
17	79690.	26730.	-0.023463	0
18	79940.	26280.	-0.036042	0
19	79760.	26410.	0.037788	0
20	80150.	26190.	-0.009724	0

THE VALUE OF F1 IS 1.2971

THE VALUE OF F IS 2.7313

THE VALUE OF K*E IS 20.4450

Figure 6 : Sample output from the program STATEST.

STATEST (fig 5) was then run to calculate the values required to test cylindricity (fig 6; appendix 4).

In many areas there were far more boreholes than outcrops and in some areas only borehole data were available. In these areas borehole data were used either to modify or define the fold axis. Following Kilby (1978, p. 31) this was done by obtaining down-plunge projection plots of all Jewel Seam subcrops for a domain and adjusting the fold axis, that is, the projection direction, until as many subcrop projections as possible became aligned. A cathode ray tube graphics terminal, which produced plots in a matter of seconds, was used to do this on a trial and error basis. For example the eight outcrops in domain 21 gave a calculated "best-fit" fold axis of 132 4. However, Jewel Seam intersections plotted using this as the projection direction displayed considerable scatter (fig 7a). This was reduced to a minimum with a projection direction of 114 5 (fig 7b) which was taken to be the fold axis for the domain. Alignment of the projections of outcrops exposing the thin, distinctive Cadomin conglomerate and Ram Member of the Cardium Formation was also used to adjust some fold axes.

Forty-five domains were established (fig 8). Table 1 and appendix 8 show which criteria were used to demonstrate cylindricity in each of these 45 domains. The potential domains that did not satisfy all criteria were nevertheless considered as cylindrical because the alternative was to subdivide them into an impracticably large number of "true"

domains. The poor degree of cylindricity in much of the area could stem from local inhomogeneities in the stratigraphic column having led to local variations in the amount of shortening through folding and therefore to rotations about axes normal and parallel to axial planes of folds. Domains exhibiting poor cylindricity, such as 14, 15 and 27, were not used in analyzing structure unless the projections of Jewel Seam subcrops or of Cadomin or Ram outcrops were consistent with cylindricity.

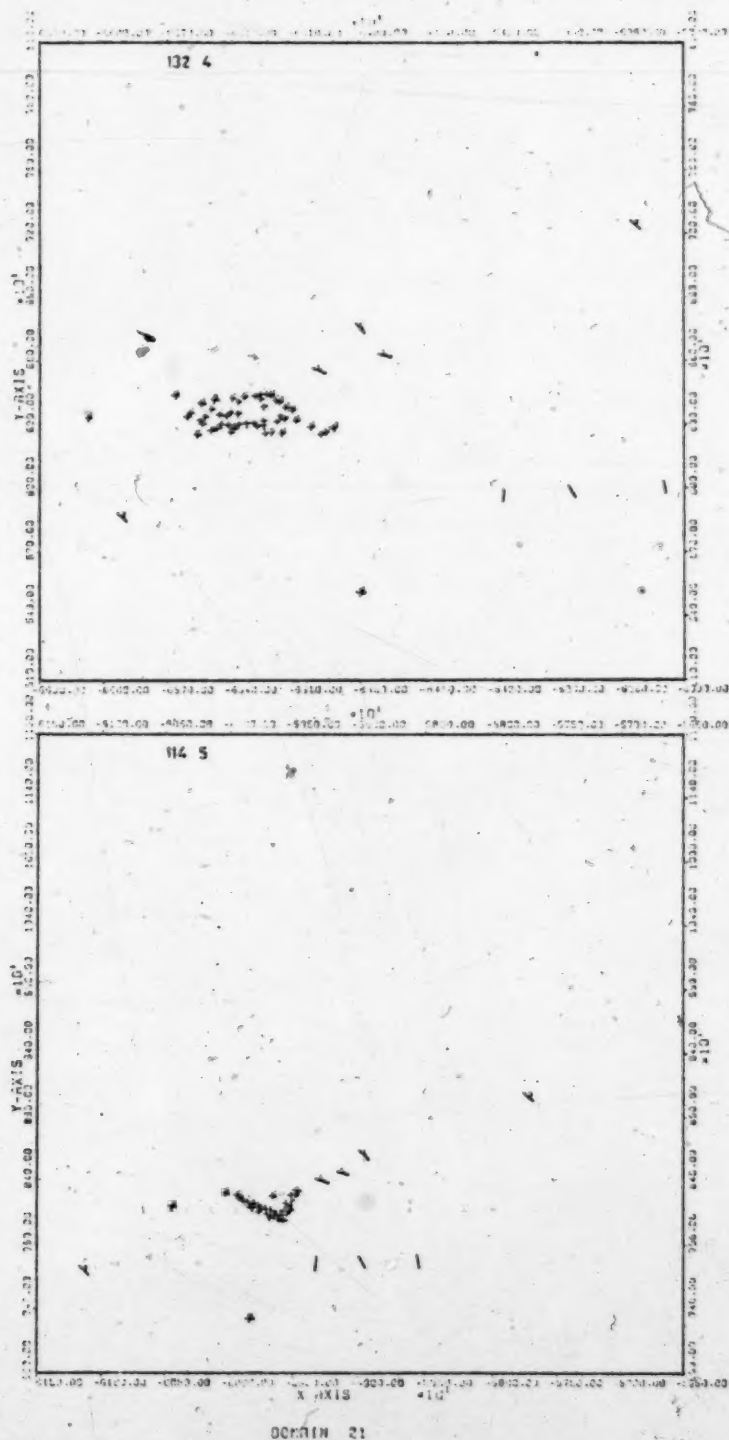


FIGURE 7: Outcrops and subcrops of domain 21 projected in two directions.

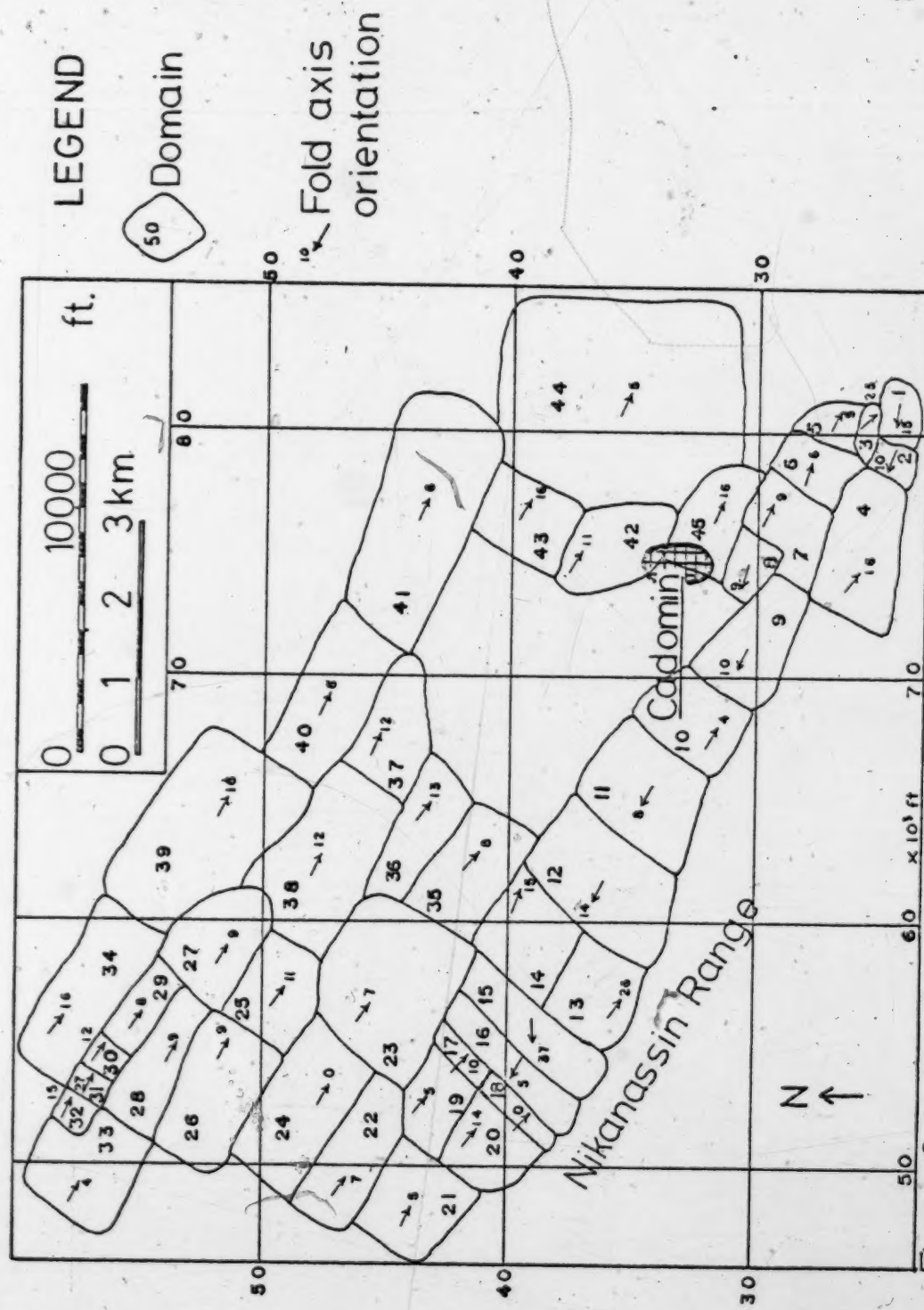


Figure 8: Location and fold axis orientation of domains

TABLE 1: Criteria used to establish cylindricity of domains.

Domain	F-Test	Chi-sq Test	Eval Test	Scatter ≤10'	Segment ≤10'
1	*	*	*	*	*
2	*	NA	*	*	*
3			*	*	
4	*	NA	?	*	*
5	*	*	*	*	*
6	*	*	*	*	*
7	*	*	*	*	*
8	*	NA	*	*	*
9	*	*	*	*	*
10	*	NA	*	*	*
11	*	*	?	*	*
12	*	NA	?	*	NA
13			*	*	
14			NA	NA	
15	*	NA	NA	*	NA
16					
17					
18					
19			*	*	
20			*	*	
21			*	*	
22			*	NA	

*=Accepted, NA=Not Accepted, Blank=No data, ?=Dubious

TABLE 1 (cont.)

Domain	F-Test	Chi-sq Test	Eval Test	Scatter ≤10'	Segment ≤10'
23	*	*	*	*	NA
24	*	NA	*	*	NA
25					
26	*	NA	*	*	*
27	*	NA	?	NA	*
28	*	NA	*	*	*
29			?	*	
30			?	*	
31			?	*	
32					
33	*	NA	*	*	*
34			*	*	
35	*	NA	*	*	*
36	*	*	*	*	*
37	*	NA	*	NA	*
38	*	NA	*	*	*
39	*	NA	*	*	NA
40	*	NA	*	*	NA
41	*	NA	*	*	*
42			*	*	
43			*	*	
44	*	NA	*	*	*
45	*	NA	*	*	*

F. Construction of Cross-Sections and Maps

As mentioned above the outcrops and subcrops in a domain can be viewed down its fold axis on a graphics terminal or using a calcomp plotter with the program SECT5 (Wrightson, 1979, pp. 15-20). This program was adapted by the author to handle up to 3000 values and to plot sections on a scale of 1:4800 which is the same as that of the basemap. The advantages of a downplunge projection are (1) that the outcrops can reasonably be projected throughout the entire domain and (2) that a true picture of the structure is obtained.

The smallness of the domains and the complexity of the structure necessitated construction of composite profiles before large-scale structures could be displayed and interpreted.

Within an area where the trends and plunges of the fold axes did not vary by extreme amounts (less than 20° and usually less than 10°) an average trend and plunge was calculated using the program EIGEN (see eg. Kilby, 1978, Pp. 28-29). Each domain was then rotated to this average value about a point in the three-dimensional centre of the domain using the program DOMROT (see eg. Kilby, 1978, Pp. 31, 115). This ensured a minimum of rotation of the whole domain. Occasionally multiple rotations were required, but care was taken to make sure that they were small.

Throughout much of the area the structure was too variable to reasonably be rotated to a common direction and

projected downplunge. As a result vertical cross-sections were constructed at 914 m (3000 ft) intervals by projecting each domain adjacent to the section along its own fold axis. The cross-sections all had an orientation of 120 90 and corresponded with the mine section lines T through G (fig 3). Relating outcrops to their projections on the vertical cross-sections enabled the geological map of fig 16 to be completed.

The cross-sections (fig 17) were constructed using the above techniques, by projecting data from domains that are either intersected by the line of section or are very close to it. The composite section was constructed across the middle of the area along the 'A' section line and rotated domains were projected onto it from both northwest and southeast. Domains spanning the 'A' section line were projected along their own fold axes; domains to the northwest were individually rotated so that their fold axes were trending towards 122° and plunging at 10° and collectively projected at 122 10, whereas the Cardium domains in the southeast were similarly rotated to and projected at 115 7. 122 10 and 115 7 are the mean orientations of the fold axes in the northwest and southeast respectively. The structure in the southwest of the composite section is particularly speculative due to the variable plunges of the domains and has been manipulated by the author to be consistent. Because of the considerable variation in fold axis orientation and in fold shape when

traced parallel to fold axes, the composite section can only be regarded as diagrammatically representative of the structure. For the vertical cross-sections, since each domain is projected along its own fold axis the structure is accurate at the topographic surface, but involves some uncertainty at depth.

III. STRATIGRAPHY

A. Introduction

Although strata ranging in age from Devonian to late Cretaceous are exposed in the Cadomin area, this study is confined to the Jurassic-Cretaceous clastic wedge sequence, with special emphasis on the Lower Cretaceous. The stratigraphic column is shown in table 2.

TABLE 2:- Stratigraphic column for the Cadomin area.

Palaeocene

Brazeau Formation

Wapiabi Formation

Upper

Cardium Formation

Cretaceous

- - - -

Blackstone Formation

Mountain Park Formation

Lower

Luscar Formation

Cadomin Formation

Nikanassin Formation

Jurassic

Fernie Group

Triassic

Spray River Group

Palaeozoic

Undivided

In the Foothills of southern Alberta, Lower Cretaceous coal is restricted to strata below the Cadomin conglomerate. In the central and northern Foothills, however, the coal is essentially confined to strata above the Cadomin. These strata were assigned by MacKay (1928, 1930), who worked in the Cadomin and Mountain Park areas, to the Luscar and Mountain Park Formations. Equivalent strata in southern Alberta were placed in the Gladstone and Beaver Mines Formations by Mellon (1967) who correlated the top of the Gladstone Formation with a marine shale in the Luscar Formation. McLean (in press) has recently revised the nomenclature of post-Cadomin Lower Cretaceous strata, redefining the Gladstone Formation of Mellon and the Mountain Park Formation of MacKay and assigning the intervening strata to the Malcolm Creek Formation. The author has here divided the Luscar Formation into Members A, B, C and D which may be broadly correlated with McLeans nomenclature (table 3).

TABLE 3

Correlation of the Authors Divisions with those of McLean
(in press)

Author's Units		McLean's Nomenclature (in press)	
Formation	Member	Member	Formation
Mountain Park			Mountain Park
-----			-----
	D	Grand Cache	
	C	Torrens	Malcolm Creek
Luscar	B	Moosebar	
	A		Gladstone
-----			-----
Cadomin			Cadomin

B. Description of strata

Palaeozoic (undivided)

The Palaeozoic rocks of the Cadomin area comprise Devonian and Mississippian carbonates and calcareous siltstones and shales. They lie at the base of the Nikanassin thrust sheet that borders the map area to the southwest (plate Ia).

Spray River Group

The Triassic Spray River Group has been divided into the Sulphur Mountain and Whitehorse Formations, the type section of the latter being located on Whitehorse Creek west of Cadomin (Best, 1958). These formations were not separated from the Palaeozoic strata, but are described separately since they commonly occur immediately above the Nikanassin Thrust.

The Sulphur Mountain Formation is approximately 300 m (1000 ft) thick and comprises brown-weathering siltstone and shale containing limestone, dolomite and calcareous or dolomitic sandstone horizons. The Whitehorse Formation consists of cream-white weathering limestone and dolomite beds, many of which are argillaceous or arenaceous. The thickness is variable due to truncation by thrust faulting and does not appear to approach the 86 m (280 ft) of the type section (Best, 1966).

Fernie Group

The Jurassic Fernie Group (Frebold, 1957) comprises a sequence of black marine shales with interbedded thin

sandstones and rare limestones. These shales have been greatly deformed by folding and faulting which has probably contributed to their highly recessive nature. The only exposures of Fernie beds within the study area occur in small contorted 'pods' directly beneath the Nikanassin Thrust and these have been mapped with the Nikanassin Formation as a single lithologic unit. The Fernie strata occurring above the Nikanassin Thrust in the northwest have not been differentiated from the underlying Triassic and Palaeozoic rocks.

Nikanassin Formation

The upper 300 m (984 ft) of the Upper Jurassic - Lower Cretaceous Nikanassin Formation are well exposed in the Cadomin railway section which was measured by Kryczka (1959). The base of the formation is elsewhere seen to be gradational into interbedded sandstones and shales at the top of the Fernie Group whilst the top is overlain unconformably by the Cadomin conglomerate (McLean, 1977). The total thickness of the Nikanassin Formation in this area was thought by Kryczka to be 421 m (1380 ft).

The Nikanassin Formation is made up of a succession of interbedded medium- to dark-grey, brown to buff weathering, very fine- to fine-grained, carbonaceous sandstones and dark grey silty shales. The sandstones can be calcareous and are commonly micaceous. On the lower slopes of the Nikanassin Range several 2-3 m thick, resistant quartzites are exposed, but these may, in part, have been indurated during movement

along the adjacent Nikanassin Thrust. The silty shales are fissile, commonly carbonaceous or micaceous and sometimes contain thin coals.

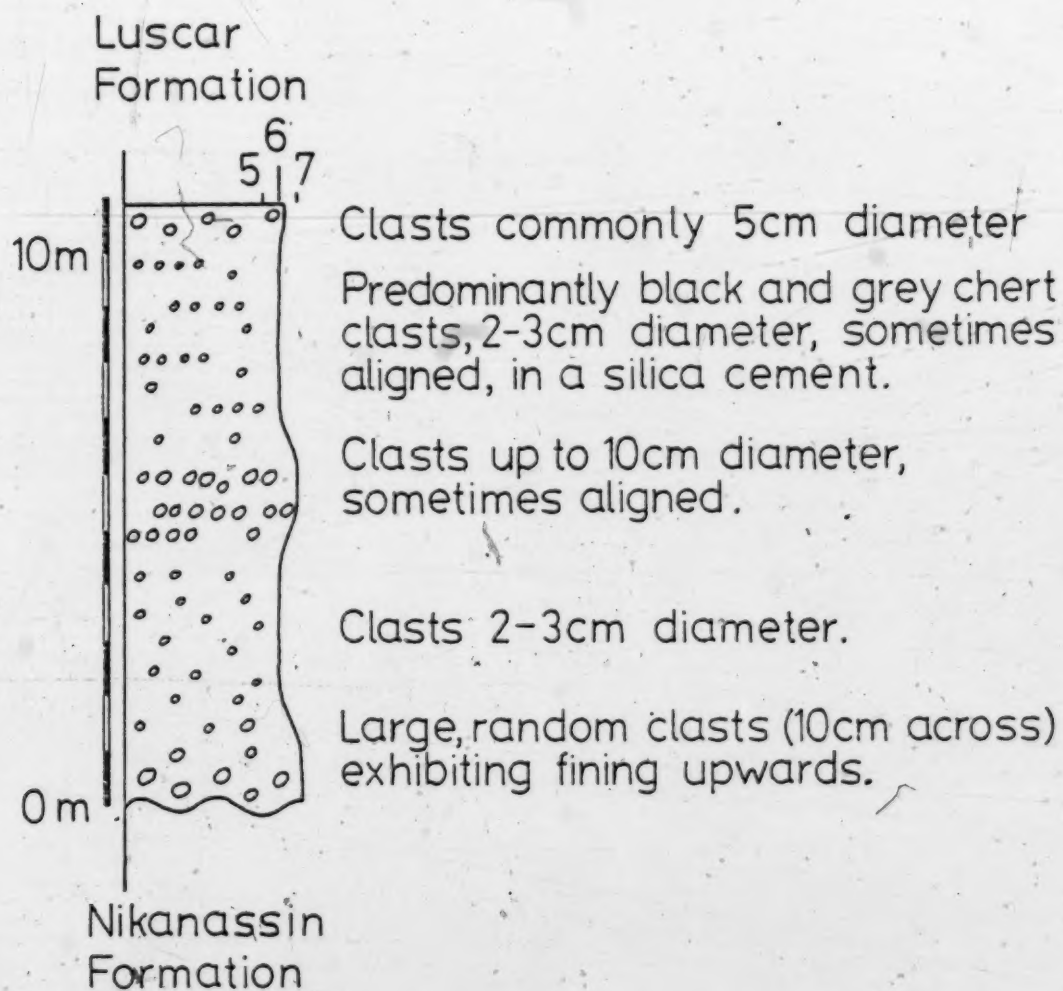
Although dominantly marine, the Nikanassin Formation was regarded by Kryczka (1959) as a regressive sequence that culminated in emergence associated with the unconformity beneath the Cadomin conglomerate.

Cadomin Formation

The Cadomin Formation consists of an 11 m (36 ft) thick conglomerate (Plate IIa) without any sandstone separations, the thickness remaining remarkably constant throughout the area. This highly resistant, ridge-forming conglomerate comprises well rounded, white quartzite and varicoloured chert clasts in a sandstone matrix so well indurated with silica that the rock fractures across clasts as easily as through matrix. The clasts are typically 2-3 cm in diameter, but coarser horizons exist with clasts commonly up to 5 cm across.

In a section measured near the Inland Cement Quarry (Plate IIa, fig 9) there are coarse, fining upward units at the base and halfway up with clasts up to 10 cm in diameter. The conglomerate is everywhere clast-supported internally and pebble alignment is common, but little or no imbrication was observed. The base of the Cadomin is erosional, being uneven and exhibiting scour, but the coarse sandstones of the overlying Luscar Formation are conformable.

The above features are typical of the Cadomin Formation



LEGEND

5. Coarse sand
6. Gravel
7. Pebble

Figure 9 : Lithologic section through the Cadomin Formation measured near the Inland Cement Quarry.

throughout its length from Fernie to northeast British Columbia (McLean, 1977), but much thicker deposits with interbedded sandstones also exist. McLean interpreted the Cadomin Formation as having accumulated over a long period by pedimentation, i.e. as a gravel lag on a smooth northeast sloping surface of erosion, lightly veneered by debris from adjacent high areas within the Omineca Crystalline Belt and Western Rocky Mountains.

Luscar Formation

The Luscar Formation, which has been divided into 4 apparently conformable members, conformably overlies the Cadomin and grades into the overlying Mountain Park Formation. The total thickness of the Luscar is estimated to be 425 m (1400 ft).

Member A

Member A (the Gladstone Formation of McLean (in press)) is about 126 m thick: the upper 96 m (315 ft) are very well exposed in the railway cutting south of Cadomin (Plate IIb, appendix 6 and fig 10) whereas the basal 30 m (100 ft) are nowhere exposed.

Member A incorporates a series of quite thinly interbedded sandstones, siltstones and shales together with thin coal seams. The sandstones are typically fine- to medium-grained and light or dark grey, but weather brown, orange or buff. They are mostly calcareous, though some are iron rich, frequently contain fossil wood and plant debris and in places contain roots at the

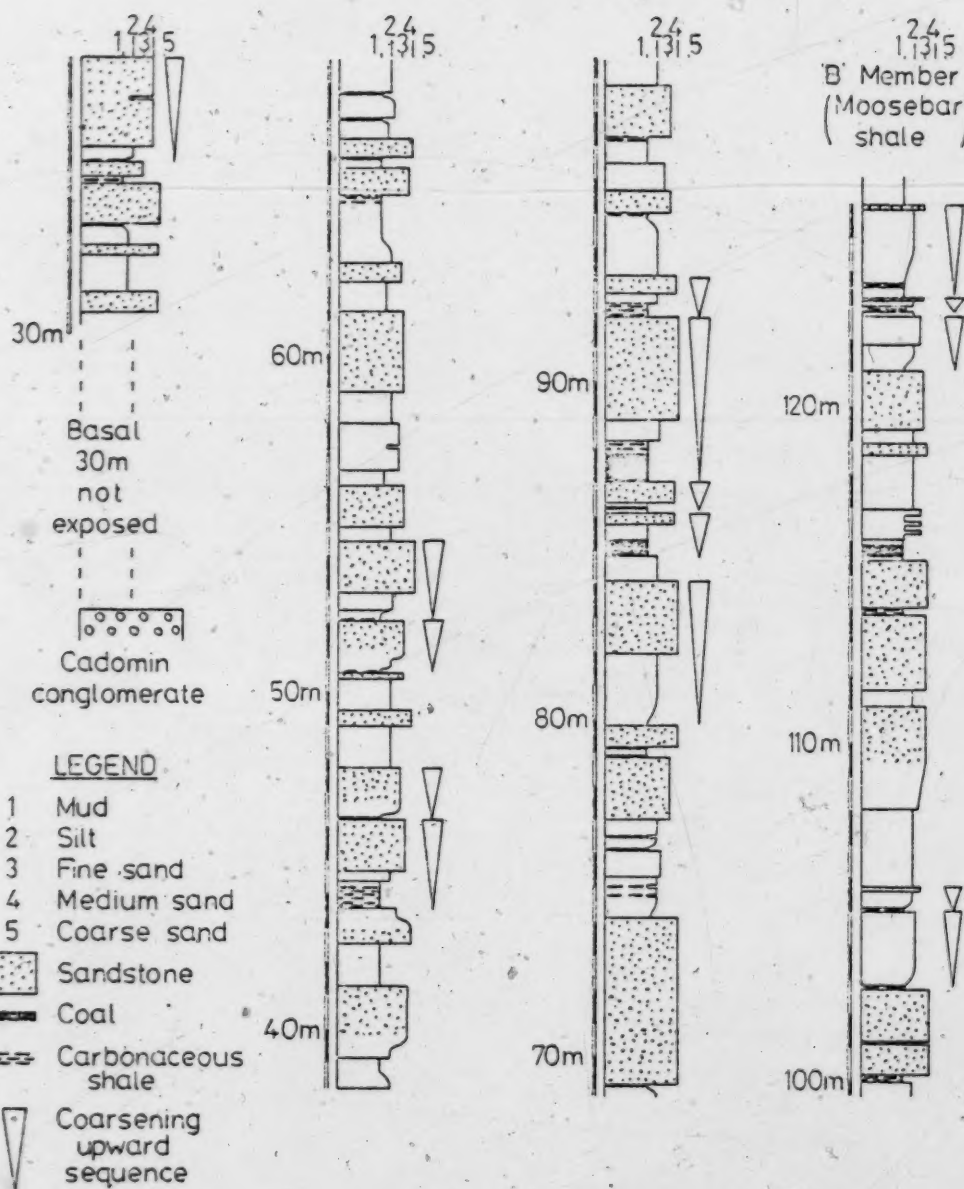


Figure 10: Lithologic section through Member A of the Luscar Formation measured along the railway cutting near Cadomin [=Gladstone Formation of McLean (in press)]

top. Sedimentary structures are not easily seen, but where visible consist of parallel laminations and fine cross-beds. The siltstones are typically fissile, dark grey or black and weathered to green, brown or buff. The shales are dark grey or black and are frequently carbonaceous, grading into coal seams. Although occasional fining upward sequences and apparently randomly interbedded sandstones and siltstones occur, coarsening upward sequences are prevalent, typically with coal or carbonaceous shale at the base and sandstone at the top.

Holter and Mellon (1972, pp. 133-4) observed coarsening upward cycles (their 'reversed cyclicity') in the Lower Luscar and concluded that, but for the lack of marine fauna, a marine or tidal flat model was applicable. However, these coarsening upward cycles are identical to those of a fluvial dominated delta, especially those of the delta plain sequence (Reading, 1978, pp. 105-107 and 125-126). Therefore this sequence of small scale coarsening upward cycles probably represents repeated infilling of interdistributary bays on a delta top. McLean (1977) postulated a post-Cadomin lake over the central Alberta Foothills dammed by the 'Smoky River Fan' to the north. He invoked this to explain the lack of thick coals south of the Smoky River and their abundance to the north. Thus, the delta may have prograded from the south and southwest into a

shallow lake which was later flooded by the boreal sea.

Member B

This member is 95 m (312 ft) thick and is exposed in the 50A3 and 51C3 pits (fig 3) where a section was measured (appendix 6 and fig 11). It consists mainly of shales (the Moosebar shales), coarsening up near the top into interbedded shales and siltstones, then siltstones and finally sandstones.

The basal shales are 18 m (60 ft) thick, dark grey and contain several 5 cm (2 in) thick limestone bands. The shales are best exposed in the southwest wall of the 50A3 pit and are only poorly exposed in the 51C3 pit. The limestone bands comprise bivalve coquinas and include Cardium and Sphaerium. Mellon and Wall (1963, p. 407) stated that these shales, where exposed in the Cadomin railway cutting (plate IIb), contain foraminifera indicative of a marine environment and correlated them with the Moosebar Formation of northeast British Columbia. The base of the shales in the railway section is marked by a coquina containing Murraia overlying a thin iron rich sandstone. The overlying shales and siltstones are poorly exposed, but where visible they are typically dark grey, fissile and sometimes orange weathering. The sandstones at the top are typically fine- to medium-grained, light or dark grey, non-calcareous, orange weathering and sometimes cross-bedded.

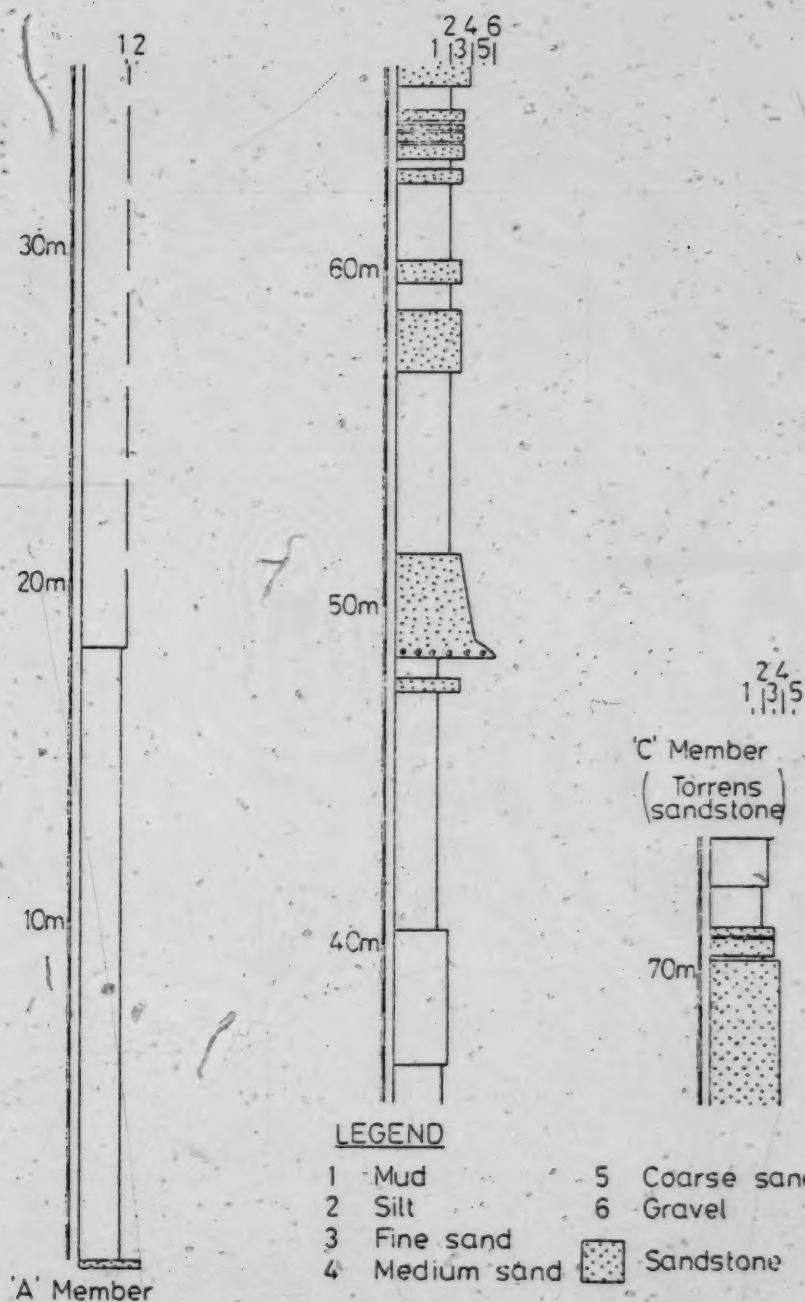


Figure 11: Lithologic section through Member B of the Luscar Formation measured in the 51C3 and 50A3 pits.

The fauna in the basal shales of Member B and the lack of coal or carbonaceous shale indicate a marine incursion of the boreal sea (Mellon, 1967, p.58). Overall, however, Member B coarsens upwards indicating a regressive sequence, the coarse sandstones of Member C and the non-marine nature of Member D lending credence to this hypothesis. The sedimentary structures and lack of plant debris in the upper 30 m (100 ft) indicate shallow marine conditions and the increasing amount of sand implies an approaching shoreline.

Member C

Member C is a 43 m (240 ft) thick, highly resistant, ridge-forming sandstone (the Torrens sandstone). It is very well exposed in all the cavings, the mine pits (plate I) and along the McLeod River and it is a distinctive marker on borehole electric logs. The member contains a thin central shale parting, the overlying sandstone being massive whereas that beneath is well bedded. The sandstone is medium-grained, light grey, buff or orange weathering and non-calcareous. It typically breaks into boulder-sized rectangular blocks and is wholly lacking in fossil wood and plant debris (appendix 6). Thin siltstones and thin, lensoid chert pebble conglomerates occur, but rarely.

Member C represents the final stages of regression of the boreal sea with subsequent emergence of the land, since the basal unit of Member D is a thick coal seam.

The lower well-bedded sandstone is likely to be shallow marine whilst the upper, thick, massive sandstone may represent a beach or barrier sand, the variable mineralogy and abundance of the sand grains reflecting the proximity of the upland source.

Member D

Member D comprises thick sandstones and siltstones, especially in the lower half, interbedded sandstones, siltstones and shales and both thick and thin coal seams. It is very well exposed in the 50A3, 51B2 and 51C3 pits (plates Ib, III; appendix 6; figs 12, 13). The upper contact was drawn at the base of the first thick, massive, channel sandstone above the highest coal seam (fig 13) giving a total thickness of 182 m (597 ft). At the base is the 12 m (40 ft) thick Jewel coal seam which has 3 thin shale partings. This is the main economic coal seam in the area and it has been and continues to be extensively mined. Its great thickness, the overlying thin shale and the underlying thick sandstone facilitate identification on borehole electric logs. The 3.5 m (12 ft) Ryder coal seam occurs 74 m above the base of the member. It is considerably more shaly than the Jewel seam and has been mined only where tectonically thickened. Although recorded on borehole electric logs it has rarely been identified on the summary sheets (fig 4).

As can be seen from figs 12-13 the member contains a series of fining upward sequences mostly dominated by

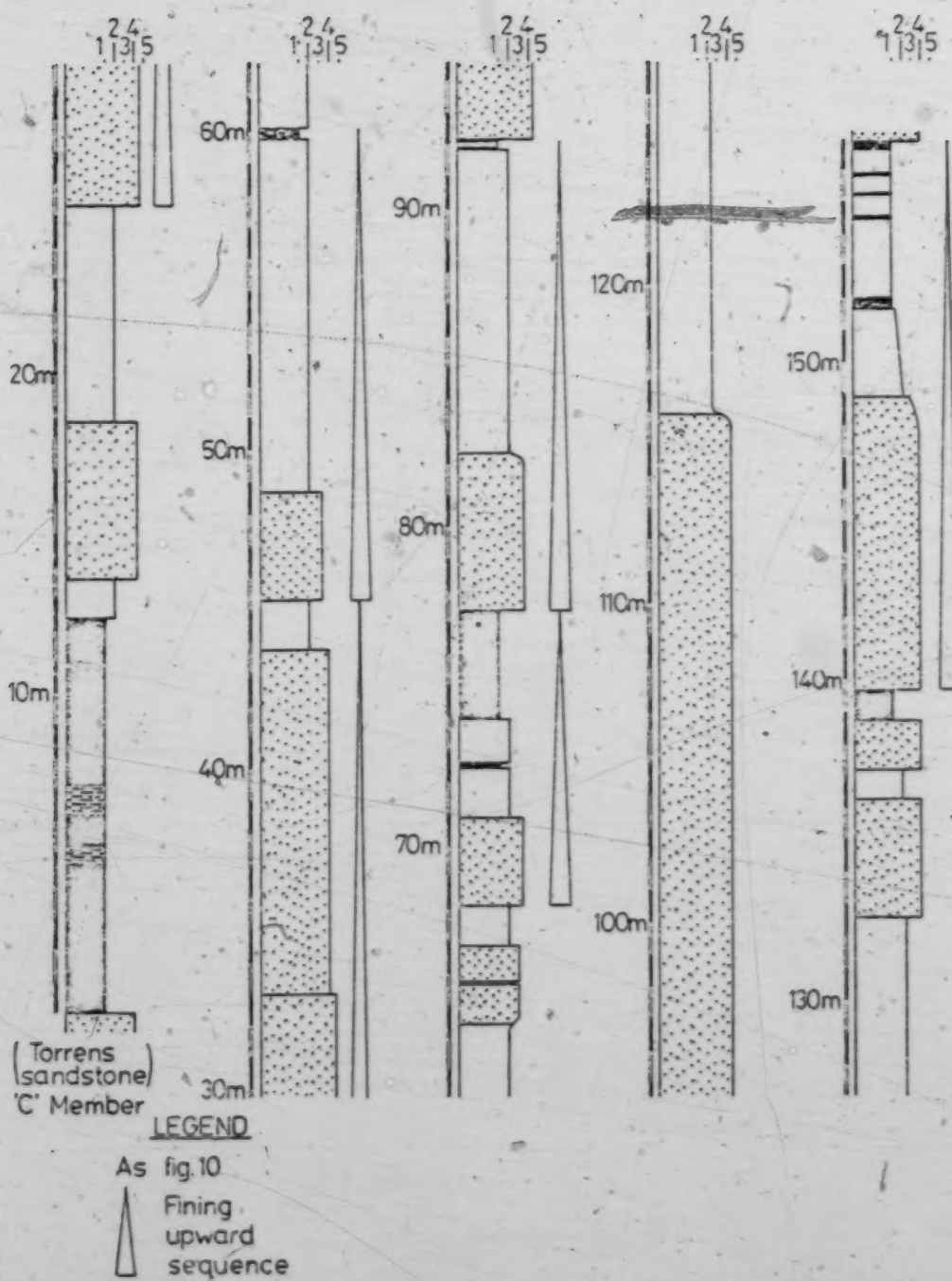


Figure 12: Lithologic section through Member D of the Luscar Formation (continued in figure 13) measured in the 51B2 pit.

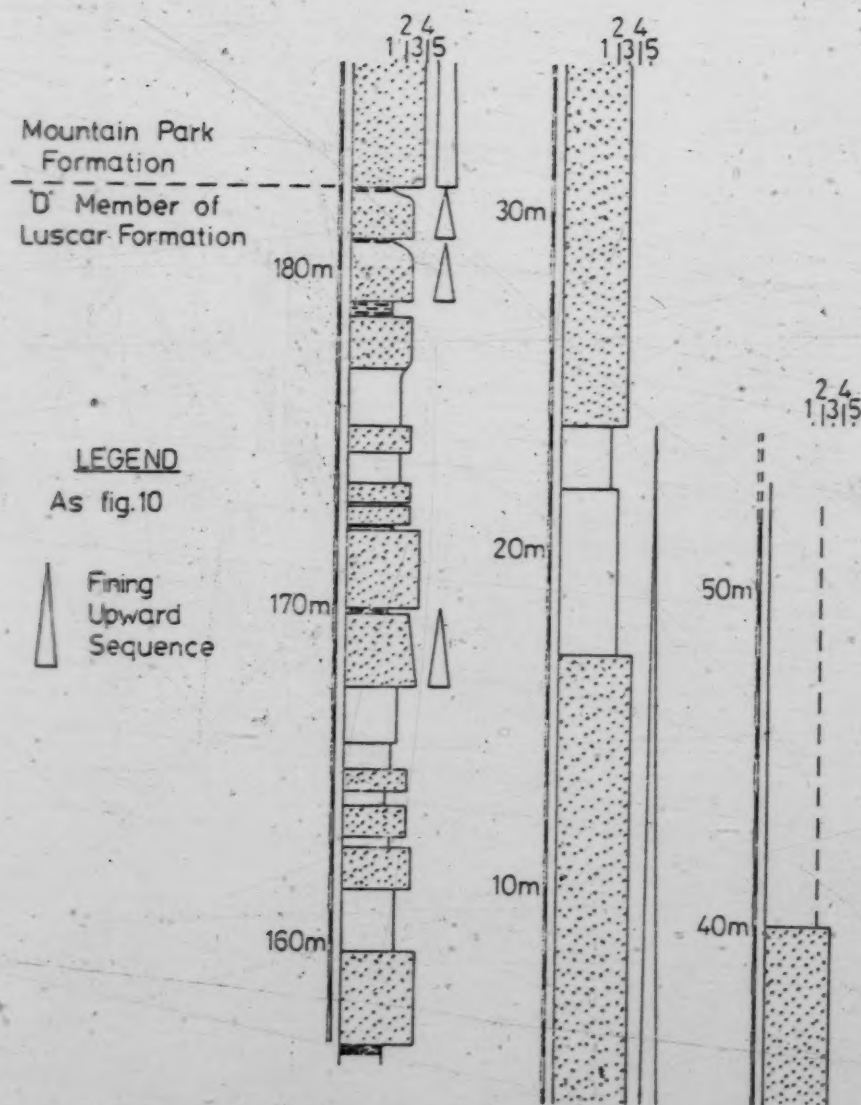


Figure 13: Lithologic section through upper Member D of the Luscar Formation and basal Mountain Park Formation measured in the 5192 pit.

the basal sandstones. The sandstones are typically light grey, weathering to orange and are mostly non-calcareous. Fine-, medium- and coarse-grained sandstones are all present and both massive and well-bedded units occur (appendix 6). Fossil wood and plant debris are abundant and some root horizons were seen. Towards the top of the member the sandstones are more grey-green being gradational into those of the Mountain Park Formation. In the lower half of the member thick, dark grey, fissile siltstones separate the sandstones, thin coal seams and carbonaceous shales occurring in or above the siltstones.

Holter and Mellon (1972, p. 133) interpret the fining upward sandstones to be channel deposits on a broad alluvial floodplain comparable to the modern Niger Delta. The interior Niger Delta consists of deep, migrating distributory channels normal to the shoreline with mangrove swamps between them. The interior delta plain sequence comprises thick channel sandstones overlain by a fining upward sequence which corresponds well with the strata of Member D (Reading, 1978, pp. 103-104).

Mountain Park Formation

The Mountain Park Formation has an average thickness, measured from profiles, of 180 m (600 ft), however, this is likely to be greater than the true thickness because of undetected internal deformation. It was defined by MacKay

(1928, 1930) to be a dark, olive green, brick-red weathering, resistant, ridge-forming sandstone containing thin lenses of black chert conglomerate. In the Cadomin area the Mountain Park Formation is characterized by massive grey-green sandstones separated by dark green siltstones and few chert pebble lenses were observed. It has a gradational contact with Member D of the Luscar Formation and is apparently unconformably overlain by the Blackstone Formation (Rudkin, 1964, P. 161). The base was defined previously and the top is only well exposed in the railway section at Cadomin. Elsewhere the upper contact was marked by the top of a thick, massive, resistant, well exposed sandstone close to the true contact.

The sandstones are commonly medium-grained, green-grey in colour and weather to green or red. They are mostly non-calcareous, contain abundant fossil plants and are strongly cross-bedded with foresets up to 1 m high. The thick sandstone units, when well exposed, are seen to be strongly channelled as in the cliff exposure of the 51B2 pit where one channel greater than 50 m (164ft) wide and 7 m (23 ft) deep was observed. The interbedded siltstones are less well exposed, but are typically dark green or grey, highly fissile and non-calcareous. The green colour is attributed to a chlorite cement whereas the underlying Luscar sandstones typically have a kaolinite or illite cement (Holter and Mellon, 1972, Pp. 128-9).

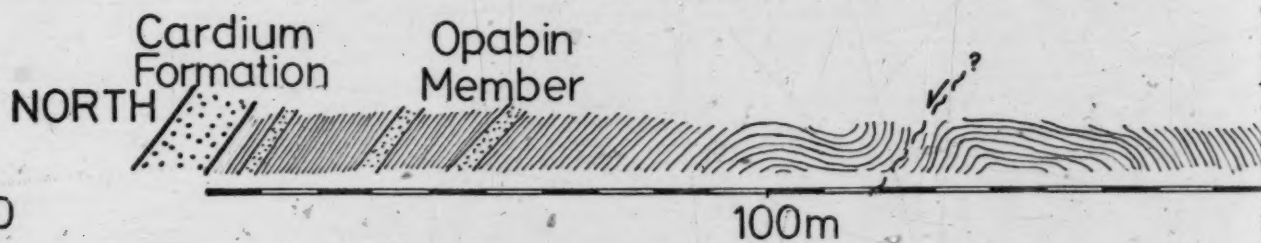
Holter and Mellon (1972, pp. 133-4) interpret the

Mountain Park Formation as being formed in a similar environment to that of the 'D' member of the Luscar, but in a higher, better drained area closer to the upland source.

Blackstone Formation

The Blackstone Formation is exposed almost continuously along a 3.7 km (2 mi) section beside the McLeod River and the adjacent railway track (fig 14). The strata are very highly deformed, so much so that neither precise correlation nor accurate thickness measurements were possible. The formation is almost entirely composed of black and grey silty shales, typically weathering a shade of grey or rust, but also contains thin, fine sandstones and siltstones and occasional thin, dolomitic limestones, particularly in the basal member. It has been divided into 4 members, the Sunkay, Vimy, Haven and Opabin Members (Stott, 1966, P. 84 and table 4) each of which can be recognized, at least in part, in the McLeod River section (fig 14). The basal Sunkay Member may overlies the Mountain Park formation unconformably (Rudkin, 1964, P. 161), whilst the Opabin Member is overlain conformably by the Cardium Formation.

Twenty-five m (80 ft) above the base of the Blackstone is a 12 m (40 ft) thick fine-grained sandstone packed with fish-scales, a horizon that is thought to mark the Albian-Cenomanian boundary (Stelck et al., 1958). The fish-scales together with the marine fauna throughout the Blackstone shales indicate a marine environment, representing the transgression and uniting of the boreal and



LEGEND

Thin sand-stone band {

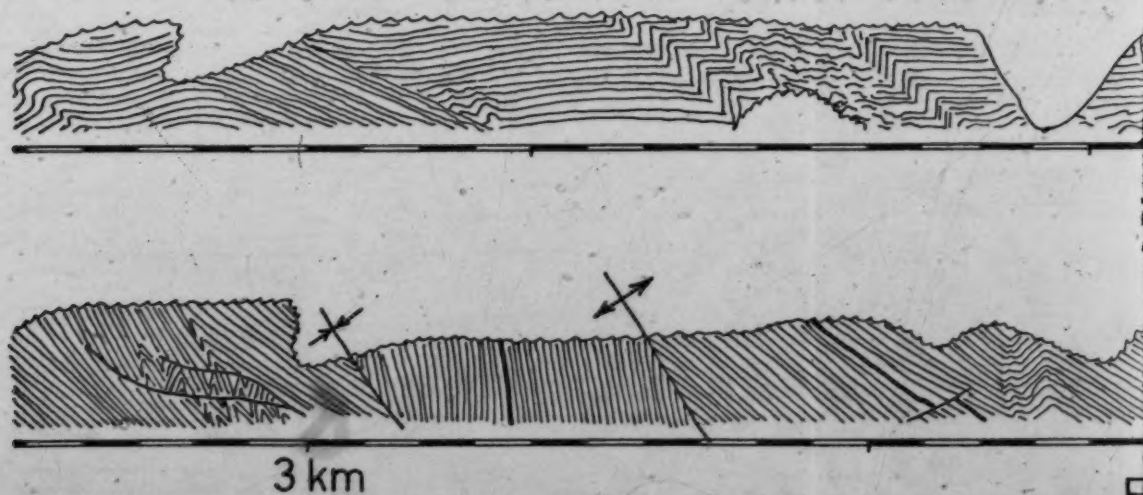
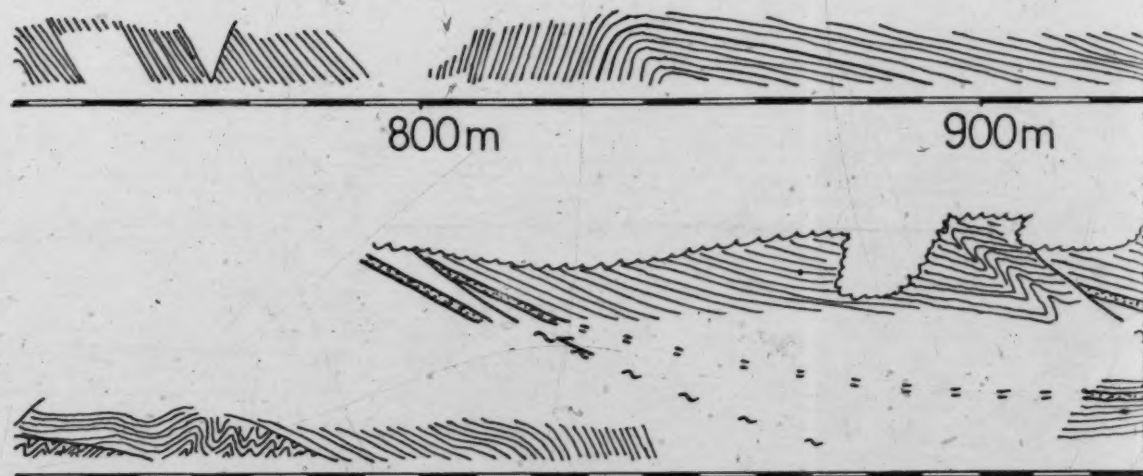
Bedding in shale

Vegetation

Fold axis

Fault

Vertical exaggeration approx. $\times 1.5$



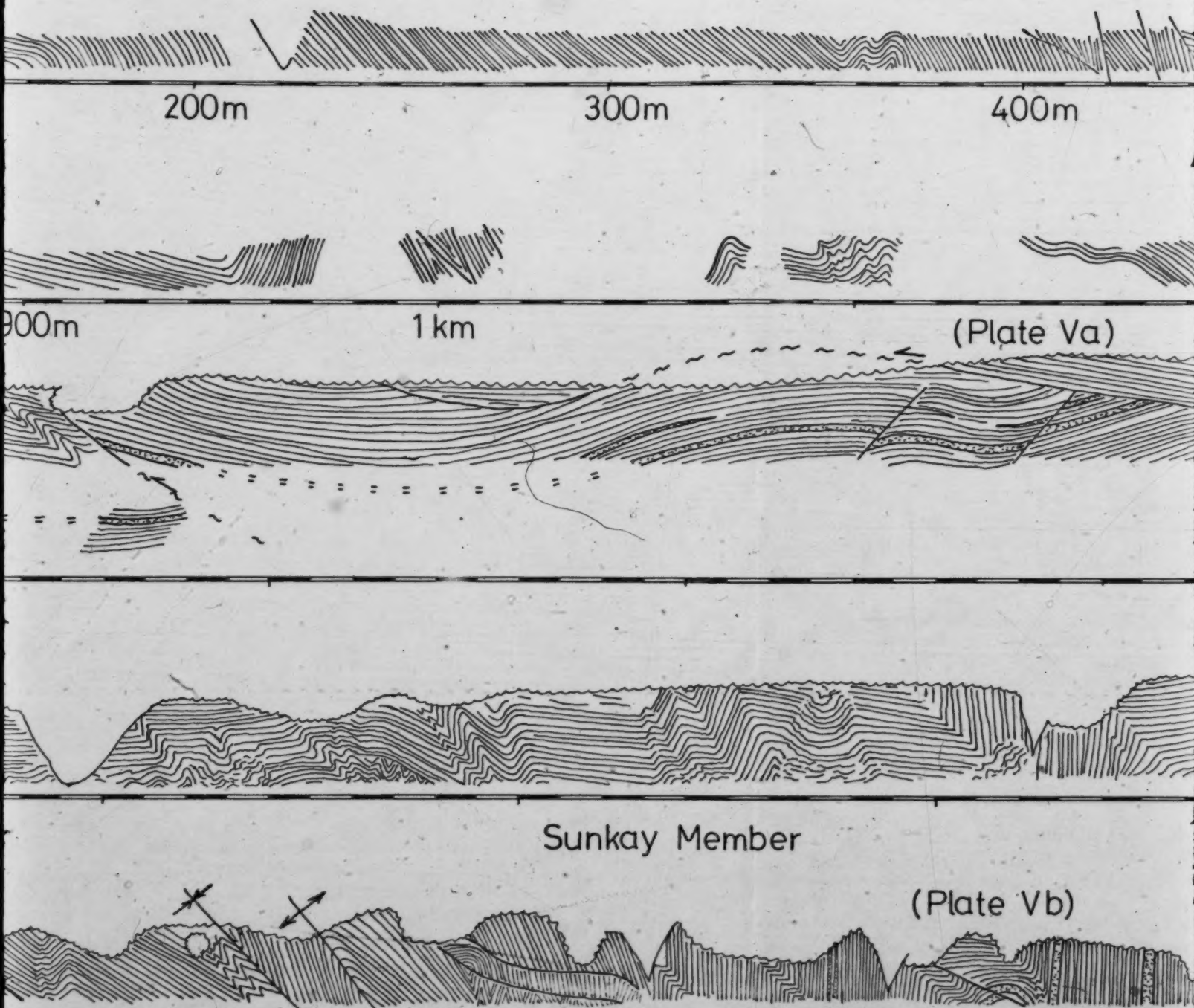
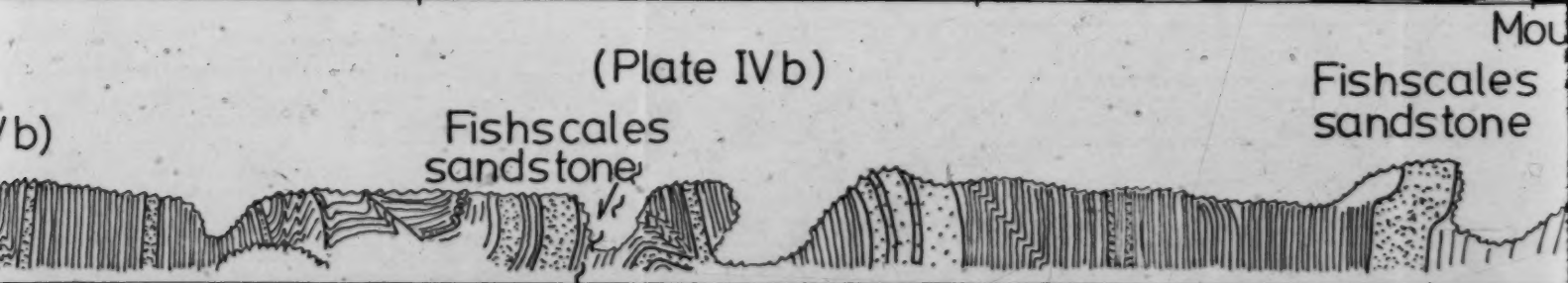
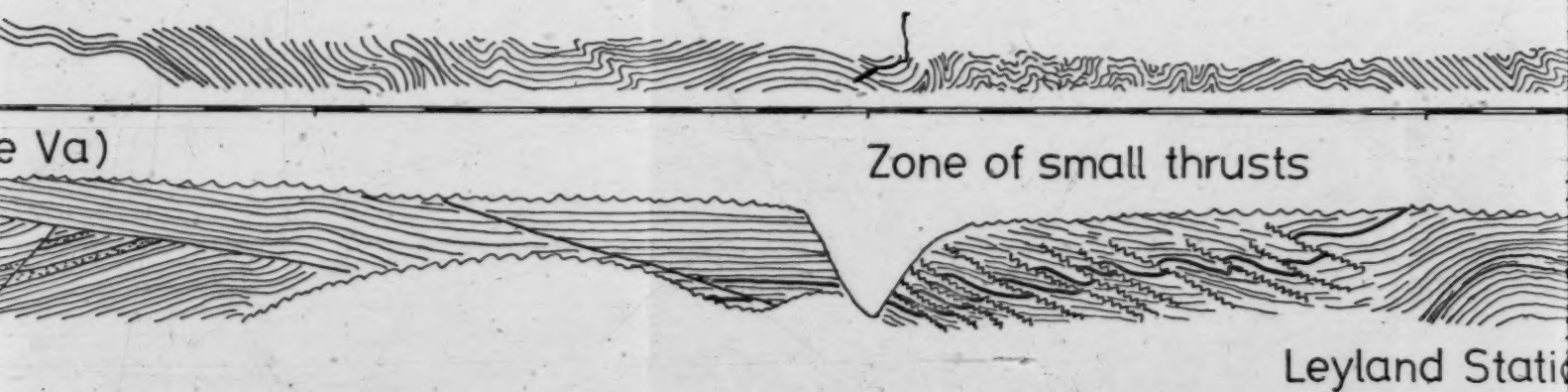


Figure 14 : Diagrammatic section through the Blackstone Formation



Formation along the McLeod River.

34



Zone of small thrusts

Leyland Station

2 km
Vimy Member

(Plate IVb)

Fishscales sandstone
Mountain Park Formation

SOUTH

McLeod River.

gulfian seas (Rudkin, 1964, P. 167).

TABLE 4:- Members of the Blackstone Formation.

Formation	Member	Estimated Thickness
Cardium		

	Opabin	50m 165ft
Blackstone	Haven	85m 280ft
	Vimy	185m 600ft
	Sunkay	215m 700ft

Mountain Park		

Cardium Formation

The Cardium Formation is very well exposed on both sides of the McLeod River to the north of the junction of Highways 40 and 47, where it has been duplicated by thrust faulting. A section was measured to the east of the McLeod River and a total thickness of 88 m (285 ft) was recorded (table 5).

The basal Ram Member is a 9 m (30 ft) thick, fine-grained sandstone that forms prominent ridges and is everywhere well exposed so that it is an excellent marker horizon. It is overlain by mudstones and argillaceous sandstones of the Moosehound Member and dark grey shales of the Leyland Member that are both poorly exposed. The Sturrock Member comprises an 8 m (26 ft) thick, basal, fine-grained sandstone overlain by 12 m (39 ft) of silty shale and finally 13 m (42 ft) of fine-grained sandstone, the upper 6 m (21 ft) of which is massive.

The environment of deposition of the Cardium is widely debated, but is considered by many to be shallow marine.

Wapiabi Formation

The Wapiabi Formation conformably overlies the Cardium Formation and comprises interbedded siltstones and shales, but was not studied in detail.

TABLE 5

Stratigraphy of the Cardium and Upper Blackstone Formations.

Formation	Member	Lithology	Thickness
Wapiabi			
	Upper Sturrock	sandstone	13m
	Middle Sturrock	shale	12m
Cardium	Lower Sturrock	sandstone	8m
	Leyland	shale	12m
	Moosehound	shale	34m
	Ram	sandstone	9m
		shale	2m
		sandstone	2.5m
		shale	10m
Blackstone	Opabin	sandstone	1m
		shale	5m
		sandstone	2m
		shale	

C. Correlation of the Lower Cretaceous Strata

Throughout much of the Alberta Foothills both the Cadomin conglomerate and the base of the Blackstone Formation are lithologically correlatable even though neither is an exact time-marker. The intervening Luscar and Mountain Park Formations can be broadly correlated throughout the central Foothills. The correlation with the nomenclature of McLean (in press) has previously been mentioned (table 3, fig 15).

The stratigraphic subdivisions of the Luscar Formation used by Wrightson (1979) at Grand Cache may be correlated with those of the author (fig 15). Wrightson's Unit A corresponds to the author's Member A whereas Unit B is equivalent to the Member B shales. The 'Salt and Pepper Sandstone' 150 m above the base of Wrightson's Unit C and the overlying #3 and #4 coal seams are correlated with the upper half of the author's Member C and the overlying Jewel Seam at the base of Member D. Wrightson's Unit D is thought to be equivalent to the Mountain Park Formation.

The Lower Cretaceous strata can also be correlated in detail with those at Mountain Park (Kilby, 1978). The 'Coquina-bearing shale interval below the Cheviot Seam' of Kilby is equivalent to the author's Member B shale, the Kennedy and Thornton coal seams are thought to correspond to the Jewel and Ryder seams, respectively, but the lower boundary of the Mountain Park Formation of each author differs slightly.

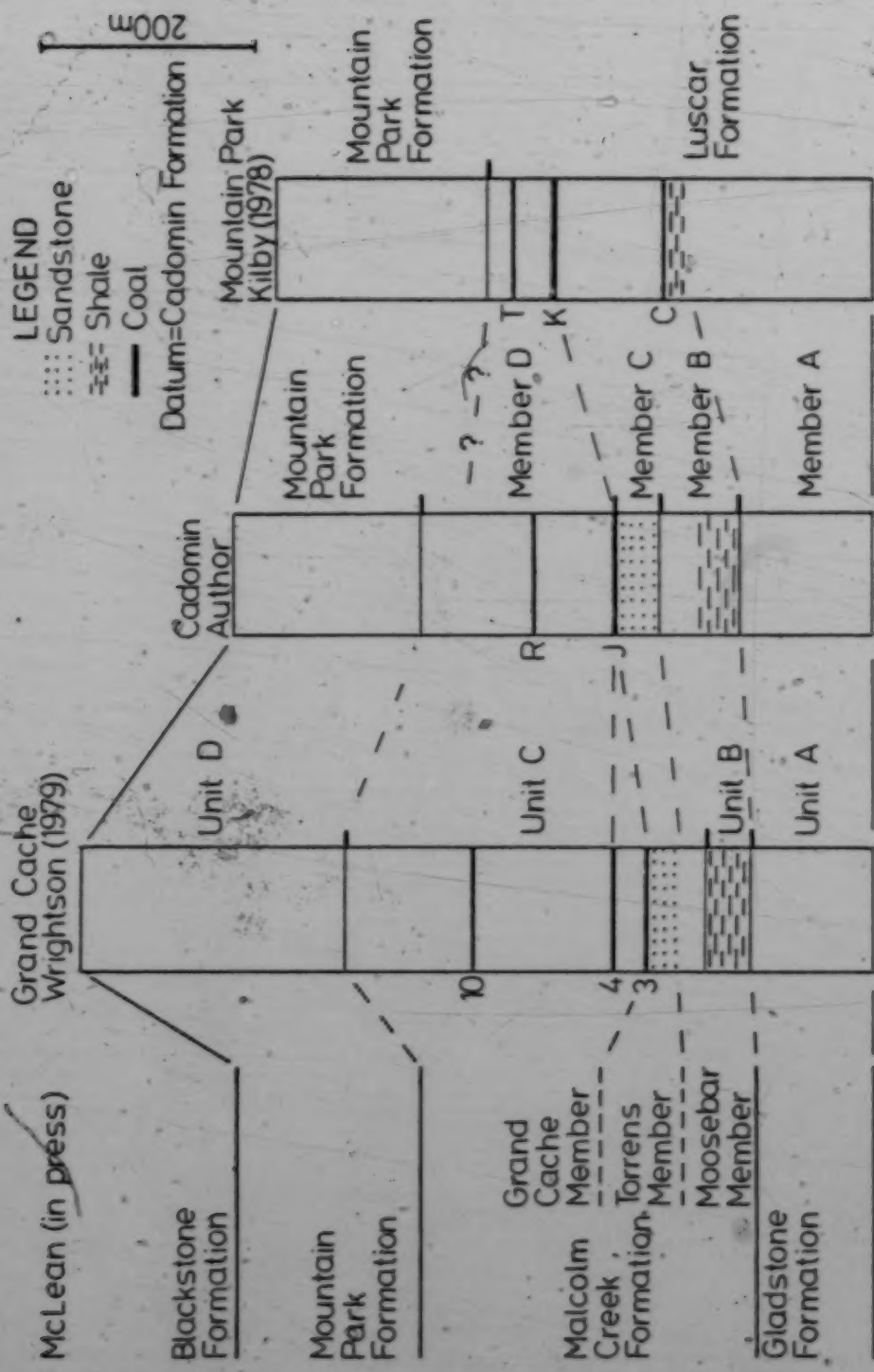


Figure 15: Correlation of the Luscar and Mountain Park Formations.

IV. STRUCTURE

A. Introduction.

Lower Cretaceous strata lie in two large folds, the Cadomin synclinorium and Luscar anticlinorium (fig 16). Apart from the Nikanassin Thrust, which bounds the synclinorium to the southwest, the only major fault to cut the strata is the Luscar Thrust which is folded by the anticlinorium. Parasitic, concentric folds 50-100 m across, that are chevron in style in the cores and are overturned to the northeast affect the synclinorium and that part of the anticlinorium in the hanging wall of the Luscar Thrust. That part of the anticlinorium in the footwall of the Luscar Thrust is characterized by parasitic folds that are upright, more open and widely spaced and by small early thrusts that cut up section to the northeast. Mesoscopic folds, up to tens of metres across, are ubiquitous throughout the area mapped. Simpler folds and major faults characterize the structure of the Cardium Formation which is underlain by a detachment zone in the Blackstone shale.

The structure of the area is shown on the geological map (fig 16), the cross-sections (fig 17) and the composite cross-section (fig 18). The domain profiles (Appendix 5) can be taken to be accurate and the cross-sections, constructed from these profiles, are accurate at the topographic surface, but involve some uncertainty at depth. The composite cross-section can only be regarded as

NE

Lower Watson Creek

Panel

Fidler
Thrust

Watson Creek
Thrust

Upper
F

Upper Lookout
Ridge Panel

Kb

Lookout
Thrust

Luscar
Anticlinorium

Kc

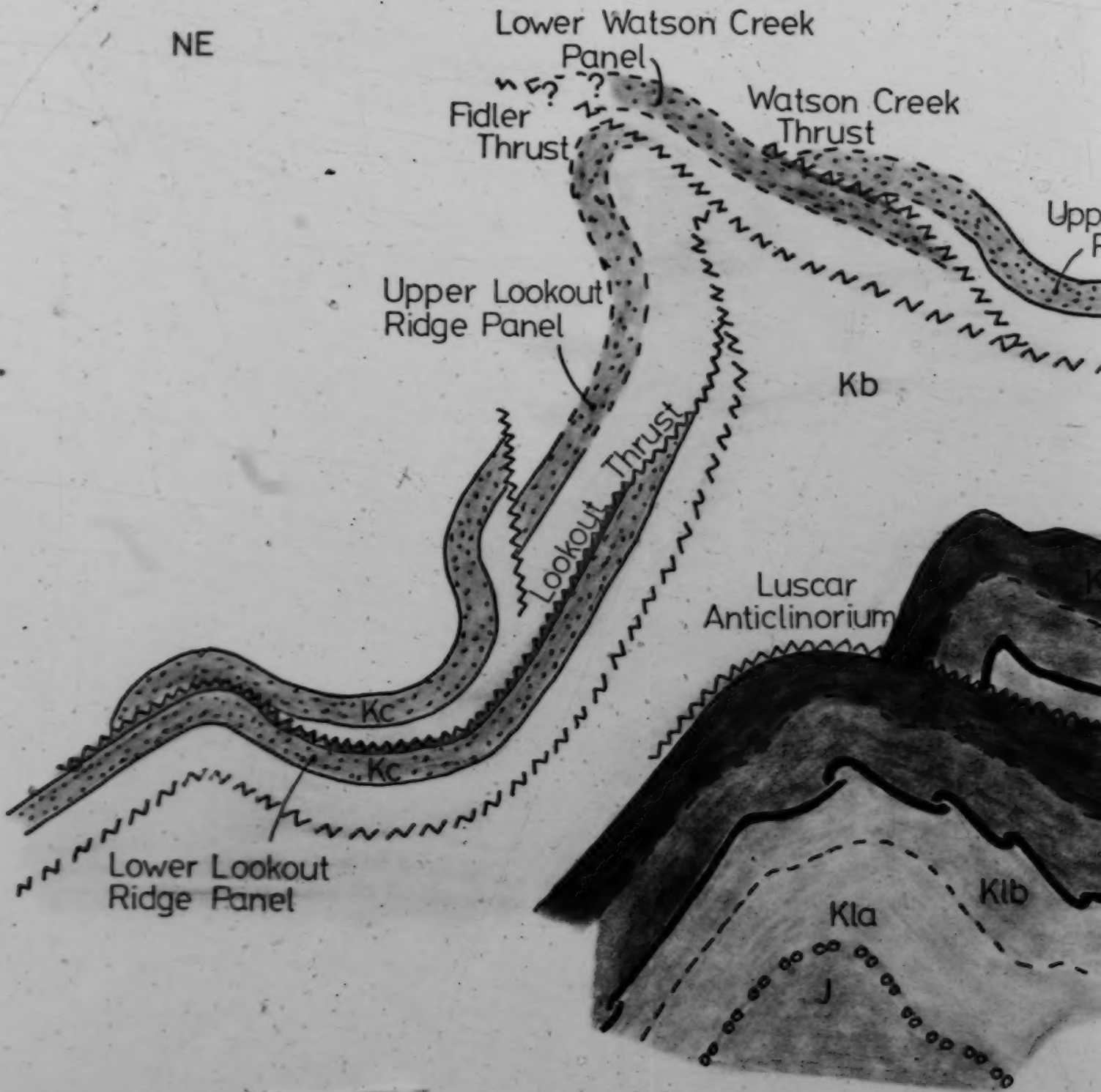
Kc

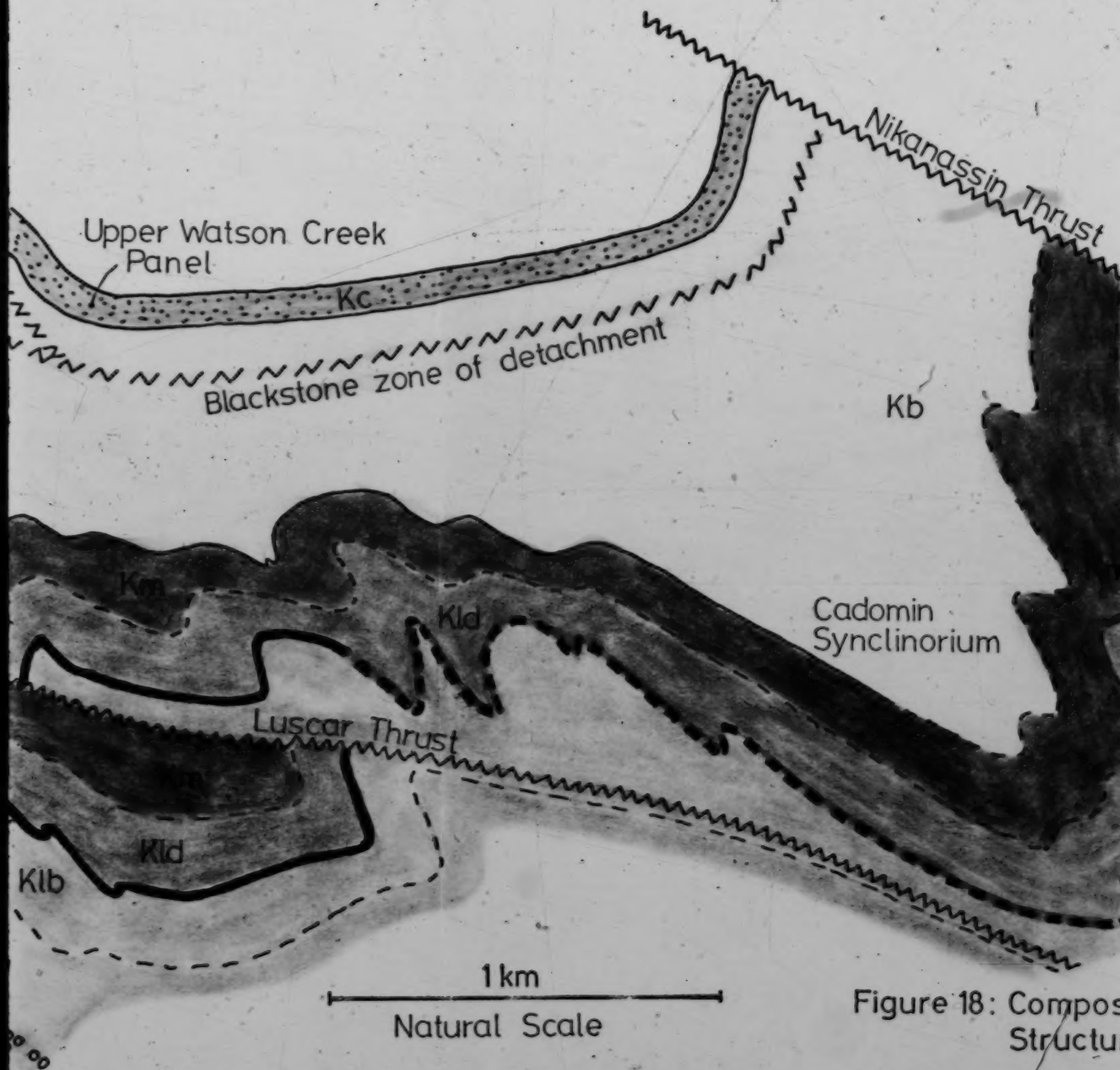
Lower Lookout
Ridge Panel

Kla

Klb

14





SW

LEGEND

Kc Cadium

Kb Blackstone

Km Mountain Park

Kld Luscar Member D

▬ Jewel Seam

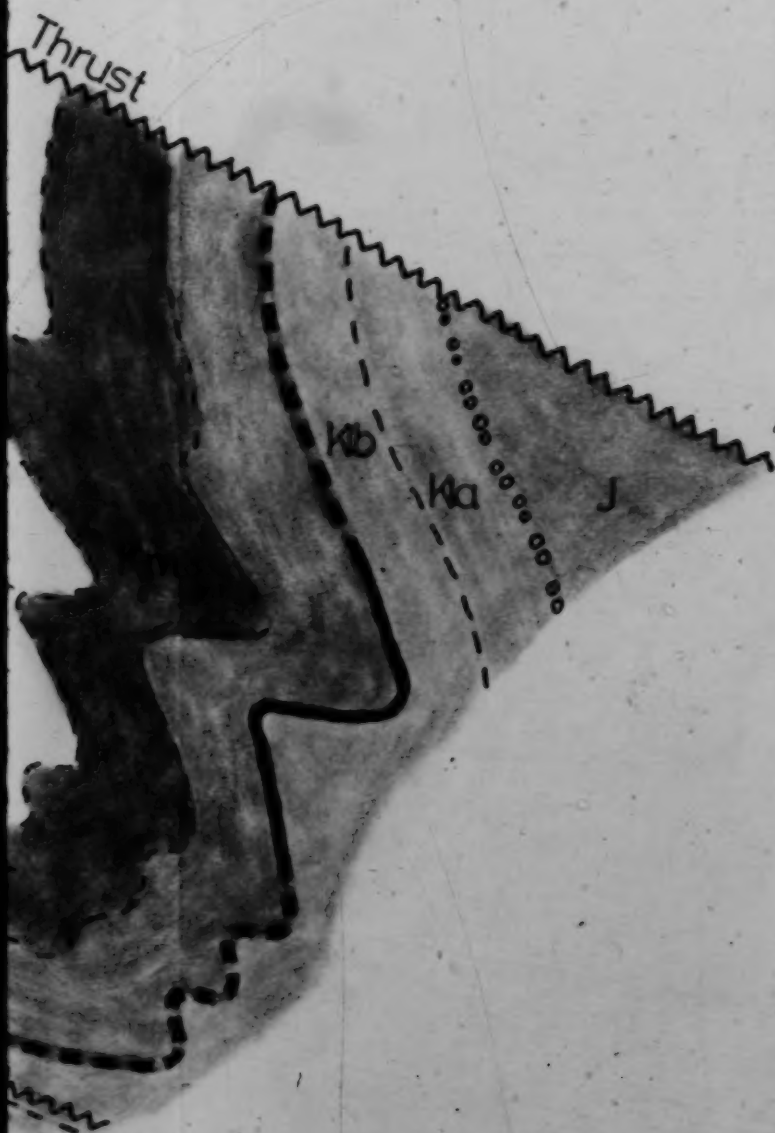
Klb Luscar Members B and C

Kla Luscar Member A

..... Cadomin

J Jurassic

~ Thrust Fault



Composite cross-section showing the
Structure of the Cadomin Area.

343

diagrammatically representative of the structure.

B. The Nikanassin Thrust

Bounding the area to the southwest, the Nikanassin Thrust is one of the major thrust faults present, in places thrusting Upper Devonian Palliser Limestone over rocks at least as recent as the Nikanassin Formation. East of the McLeod River, gently southwesterly dipping Palliser strata, that are the right way up, constitute its hanging wall. However, west of the McLeod River, these are replaced by northeast facing Devonian-Jurassic strata. Overturned, southwesterly dipping Nikanassin beds generally underlie the thrust, although in places, such as along the McLeod River, 'pods' of Fernie shale occur. From outcrop data and structural profiles the orientation of the Nikanassin Thrust was determined to be approximately 210.30 (fig 17a). Small thrusts associated with the Nikanassin Thrust may occur in Nikanassin strata of the footwall.

C. Lower Cretaceous strata above the Luscar Thrust

Most Lower Cretaceous strata in the hanging wall of the Luscar Thrust lie in the Cadomin synclinorium and in the southwest limb of the Luscar anticlinorium.

The Cadomin synclinorium is developed mainly in Nikanassin-Mountain Park strata. Its overturned southwest limb is well exposed on the lower slopes of the Nikanassin Range and along the McLeod River. Although the overall

plunge of the synclinorium is gentle and to the southeast on a large scale, folding is non-cylindrical in the southwest limb where 21 domains, many of them plunging northwest, had to be established (fig 8). Non-cylindricity is further demonstrated by the wide variation in trend and plunge of the mesoscopic fold axes which do not, in general, coincide with the macroscopic fold axes (figs 2 and 8). The axial surfaces of parasitic folds dip southwest at 50° - 60° ; the folds tend to be chevron in style (plate IVa), particularly near the cores, with apical angles between 30° and 70° , but sometimes approaching 0° .

The parasitic folds are best exposed at the level of the Jewel Seam particularly in the 50A3 pit and near the line of cavings; they are also well defined by borehole data from the mine area (fig 19). In the 50A3 pit a closed anticline-syncline fold pair is visible (plate Ib and fig 17c). Although the axial surface orientation is fairly constant the fold axis orientation is variable as demonstrated by there having to be 5 domains in the 50A3 pit area. On both sides of the McLeod River a tight to isoclinal anticline-syncline pair (fig 20) is clearly seen on aerial photographs. It is also very well exposed in Member A of the Luscar Formation in the railway section (plates IIb, IVa and fig 17a). Although the folds of the McLeod River are tighter than those of the 50A3 pit the sense of folding is the same and they may well be continuous with one another. This implies that the plunge is towards the northeast between the

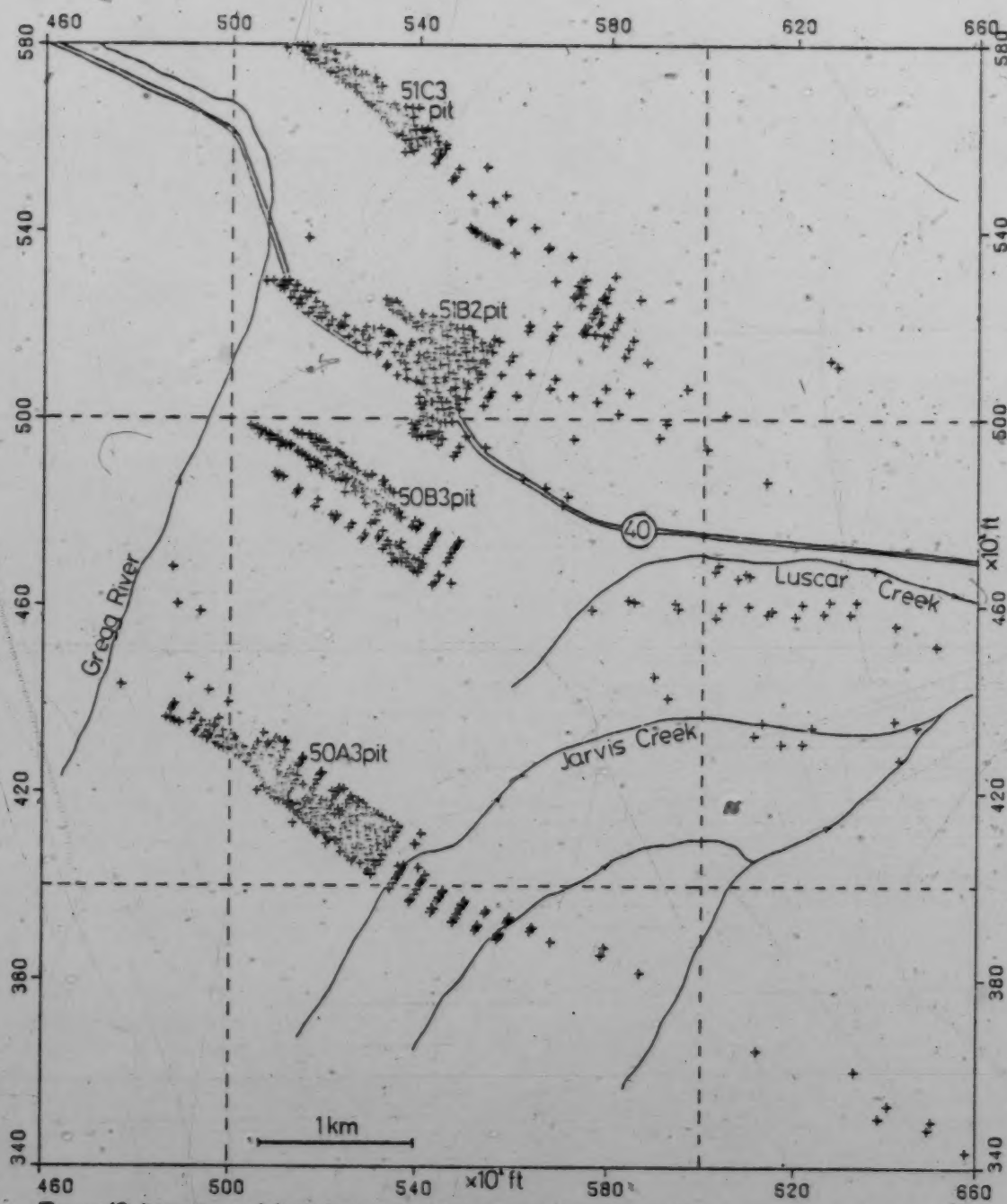


Figure 19: Location of boreholes that intersect the Jewel Seam.

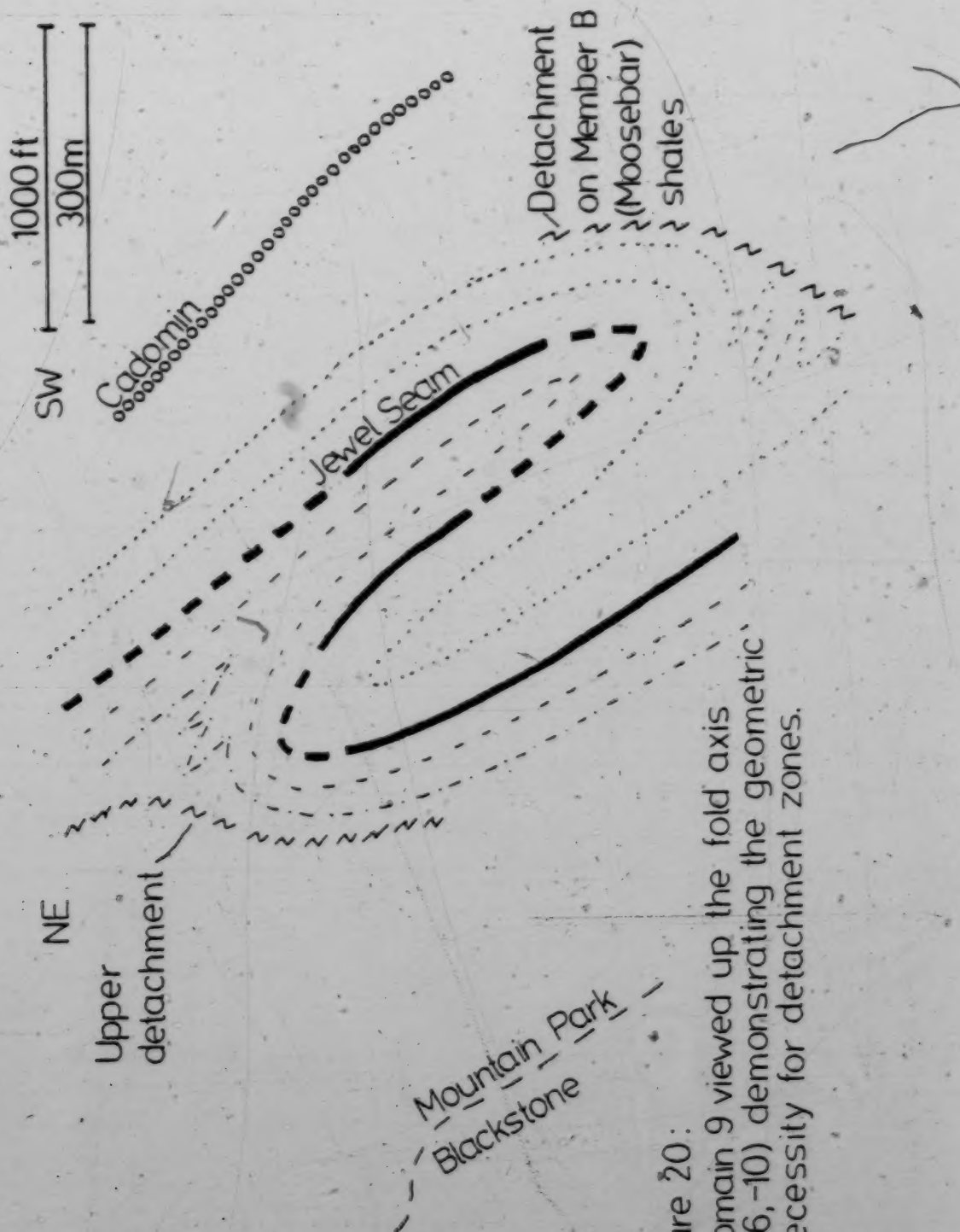


Figure 20:
Domain 9 viewed up the fold axis
(116,-10) demonstrating the geometric
necessity for detachment zones.

B-B' section line and the river which is substantiated by the orientation of the fold axes of domains 9, 11 and 12 (fig 8).

In all the parasitic folds the coal is very much thickened near the hinges and thinned in the limbs. The different styles of deformation of the incompetent coal and the competent (Torrens) sandstone of the Luscar 'C' Member beneath it are well developed in the easternmost pit east of the McLeod River (fig 24b). The sandstone forms a round, concentric fold whilst the coal forms a big pod above it, with highly complex mesoscopic folds within the pod.

The core of the synclinorium is obscured by mine spoil heaps and exposure in the Gregg River is poor. However, the exposures of the Mountain Park Formation on the ridges and in the Gregg River, together with the few boreholes that intersect the Jewel Seam indicate that the core of the synclinorium is complexly folded.

Although some of the parasitic folds may continue parallel to fold axes for several kilometres their vertical continuity is often limited. This is well illustrated by the anticline-syncline pair in the Jewel Seam immediately west of the McLeod River (fig 20). If the beds above and below the coal are sketched in a space problem becomes apparent and detachments are necessitated so that the structure dies out or is replaced by a fault (Dahlstrom, 1970). Hence the trace of the axial surface of the anticline dies out on the map.

East of the McLeod River the Jewel Seam is truncated by a fault such that it is immediately overlain by Cadomin conglomerate (fig 17a). The fault appears to be a forelimb thrust such that the displacement of the overturned limb of the Cadomin conglomerate is in the order of 240 m, but the horizontal fold limb indicates a displacement in the order of 600 m. A similar style small fault occurs southeast of the 50A3 pit (fig 21) though the displacement is only a few tens of metres.

The northeast limb of the Cadomin synclinorium and the southwest limb of the Luscar anticlinorium comprise the hanging wall of the Luscar Thrust. Exposures of the Lower Cretaceous strata in the hanging wall are good along Luscar Creek and its tributaries and in the 51B3 pits, but are otherwise scarce. Boreholes provide excellent subsurface control in the mine but are lacking to the southeast, there being few boreholes southeast of Jarvis Creek (fig 19).

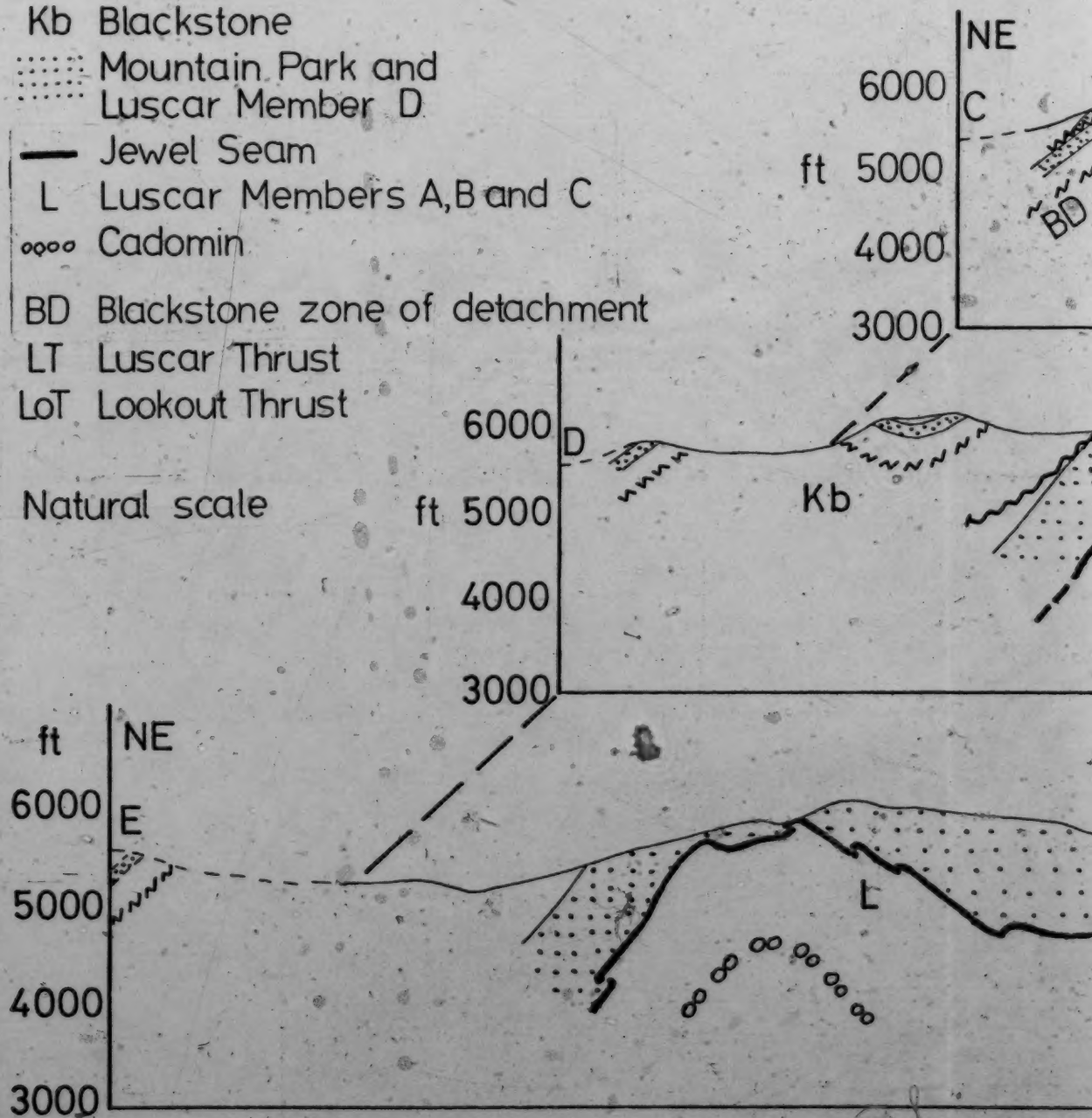
The strata in the hanging wall are involved in numerous complex folds whose plunge and geometry are highly variable (fig 21). The folds typically have the same vergent style as those in the southwest limb of the Cadomin synclinorium with both limbs dipping to the southwest and the axial surface dipping 60° - 80° in the same direction. Incompetent rocks such as coal are commonly tightly to isoclinally folded with sharp anticlinal and synclinal cores in which the coal is concentrated in thickened pods. On the other hand competent units, such as the massive Mountain Park sandstones, are

Figure 21: Longitudinal (down-plunge) variations in structure on the B, C, D and E section lines.

LEGEND

-  Cardium
- Kb Blackstone
-  Mountain Park and Luscar Member D
-  Jewel Seam
- L Luscar Members A, B and C
-  Cadomin
- BD Blackstone zone of detachment
- LT Luscar Thrust
- LoT Lookout Thrust

Natural scale

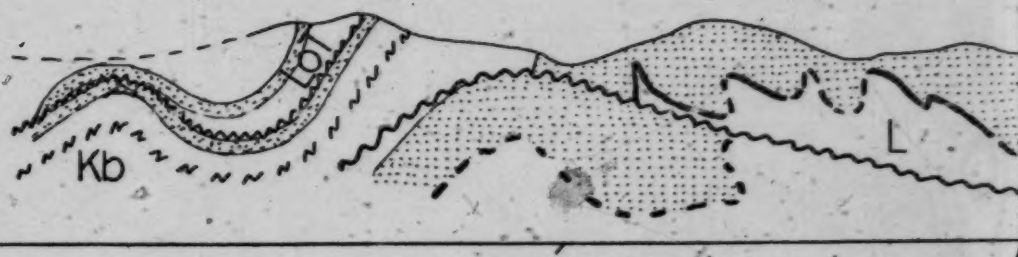


14

in structure

6000
ft
5000
4000
3000

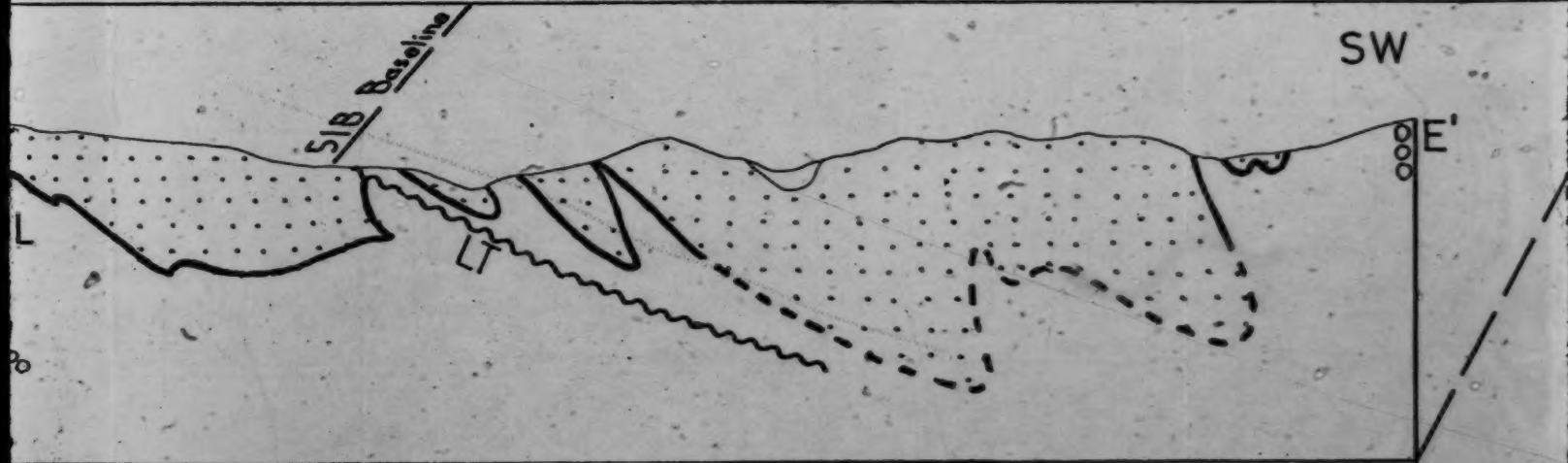
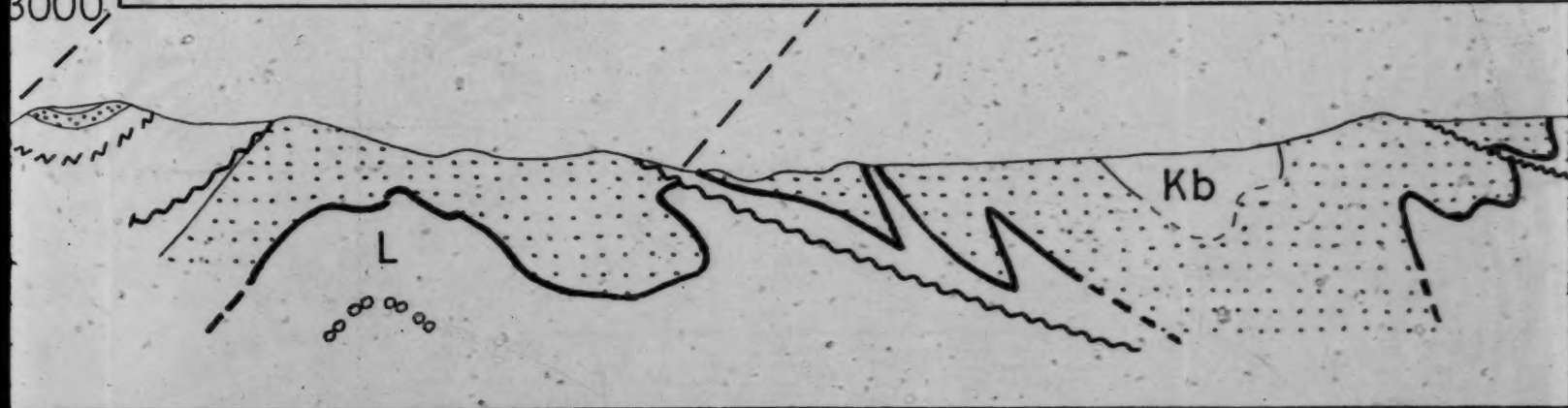
B



NE

6000
5000
4000
3000

C



24

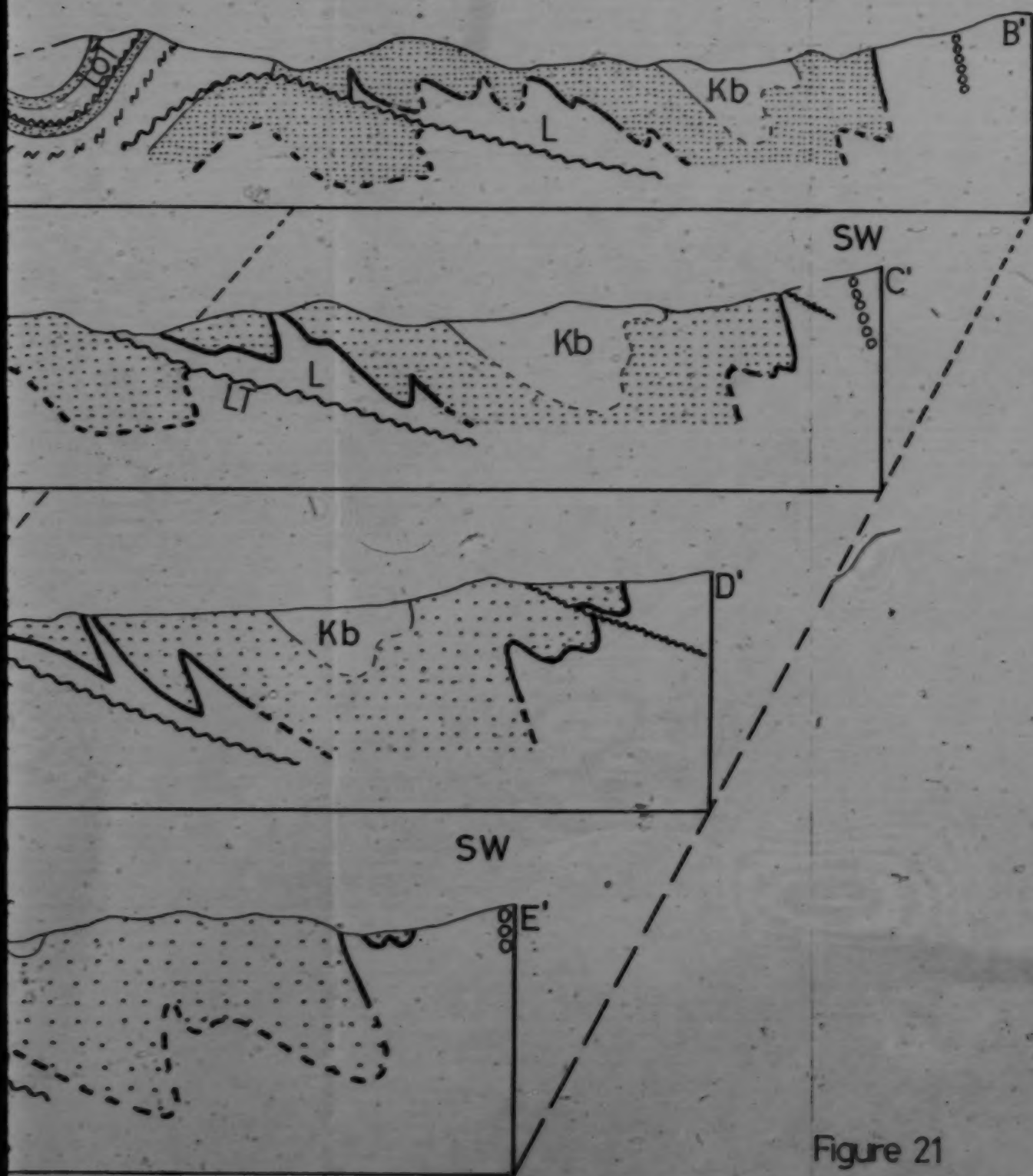


Figure 21

more openly folded. The apparent difference in shortening is compensated for by the thinning and stretching of the limbs of folds in incompetent rocks. The lack of structural continuity is shown by the coal in fig 21 where the 2 major anticlines on the 'E' section line merge into a series of anticlines and synclines of lower amplitude on the 'B' section line.

Although domain fold axes in the northwest consistently plunge down to the southeast, when each domain is independently projected onto cross-sections the fold axes are found to plunge down to the northwest between the 'B' and 'D' section lines. Support for this reverse in plunge was found in the domains in the southwest of the area and in the mesoscopic fold axes orientations (fig 2). Domains 15 and 16 (fig 8) lie between the 'C' and 'D' section lines and their fold axes plunge down to the northwest. The fact that the southwestern domains can be used as a guide to the structure of the area to the northeast has important implications for the area northwest of Cadomin that is underlain by Blackstone Formation and is devoid of both exposures and boreholes (see Economic Implications).

D. Luscar Thrust

The Luscar Thrust is only evidenced in outcrop at the southern end of the 51B2 pit high-wall (Plate IIIa) where the strata directly beneath it are highly deformed (fig 22). Elsewhere, its existence is inferred from the duplication of

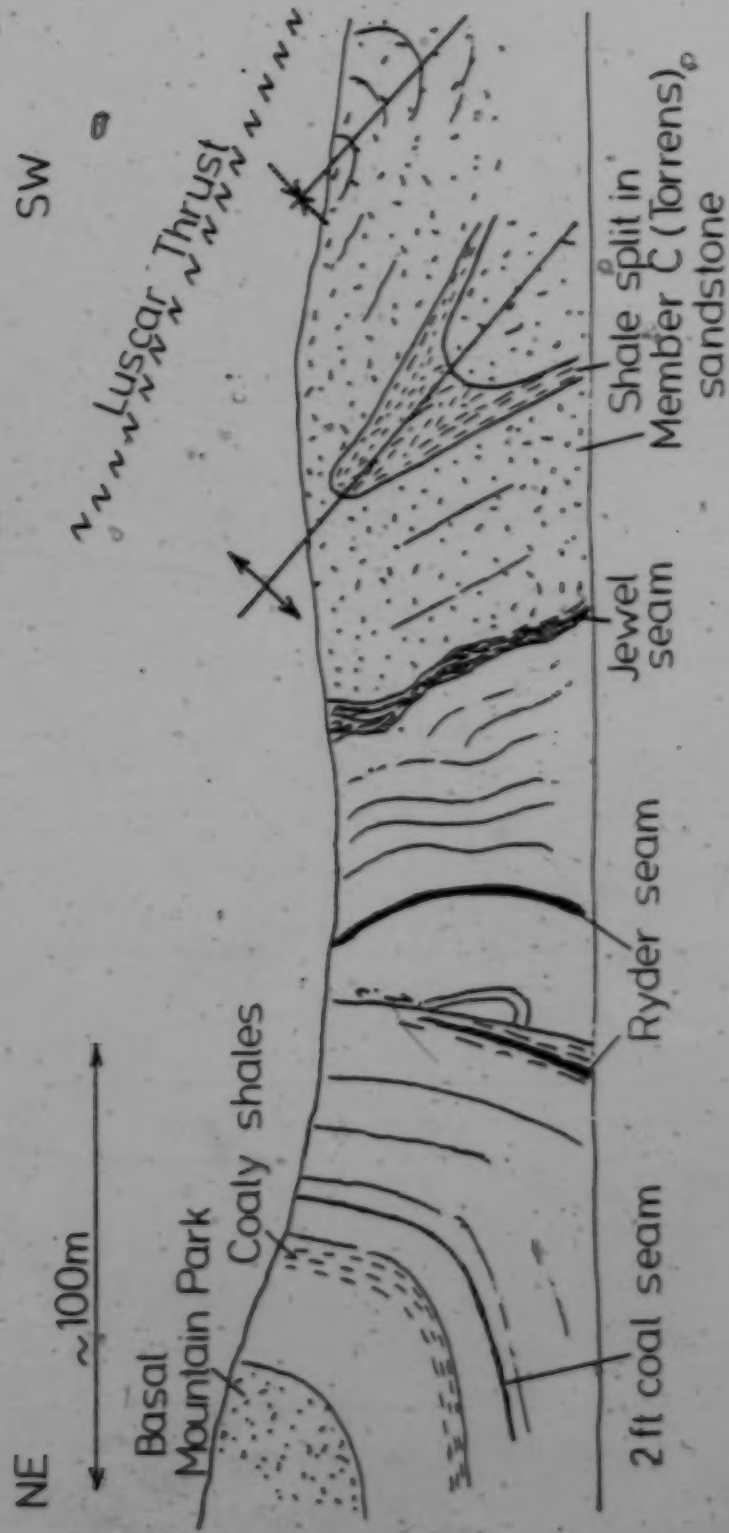


Figure 22: Sketch of the structure at the southern end of the 51B2 pit (simplified and not to scale)

strata, particularly the Jewel Seam, as determined from borehole data. Displacement along the fault, using the Jewel Seam as a marker, is about 730m (2400ft).

The southwest segment of the thrust is approximately parallel to bedding in the (Moosebar) shales of the 'B' Member of the Luscar Formation in the hanging wall. To the southeast of the 51B2 pit the trace of the Luscar Thrust runs parallel to and northeast of Luscar Creek as is evidenced by both outcrop and subcrop of the Jewel Seam in the hanging wall of the fault. The southwest segment of the fault flattens out in this direction (fig 21) dipping 30° southwest on the 'F' section line and 15° southwest on the 'B' section line. This change in dip is shown by a kink in the fault trace on the map that corresponds with a kink in the hanging wall of the Luscar Thrust.

To the northeast the fault cuts across the Upper Luscar and Mountain Park Formations at about 90° to bedding in both hanging wall and footwall. In the footwall it cuts across the top of the Mountain Park Formation on the southwest limb of the Luscar anticlinorium and then parallels bedding near the base of the Blackstone Formation so that it dips down to the northeast. This interpretation is supported by the failure of the Luscar Thrust to cut the steeply dipping Cardium Formation to the northeast (fig 18) and by the anticlinal nature of the overlying Blackstone Detachment and associated splays (see Cardium Structure).

E. Lower Cretaceous strata below the Luscar Thrust

Strata ranging from the uppermost Nikanassin Formation to the lowermost Blackstone Formation are exposed in the Luscar anticlinorium beneath the Luscar Thrust (figs 17c and d). The structures of the Upper Luscar and Mountain Park Formations are very well exposed in both the 51B2 and 51C3 pits (plate III) whilst the Nikanassin, Cadomin and Lower Luscar Formations are less well exposed in the Gregg River valley to the northwest.

The Jewel Seam in both limbs of the anticlinorium has been shown from both borehole and outcrop data to be cut by numerous small faults with a few tens of metres displacement (fig 17c). These cut up section at low angles to the northeast so that in the southwest and northeast limbs of the anticlinorium they tend to dip southwest and northeast respectively (plate IIIb). This is NOT analagous to the 'S' and 'Z' shaped folds found on the limbs of anticlinoria when both anticline and parasitic folds are formed by the same event. On the contrary, the consistent direction of displacement along the small faults indicates that they were not synchronous with folding, but were pre-folding.

The anticlinorium is associated with a flat-bottomed syncline in the 51B2 pit (plate IIIa) with an overturned limb in the southwest, adjacent to the Luscar Thrust. Apart from this overturned limb, in both the anticlinorium and its parasitic folds the style of folding is open to gentle and upright (Fleuty, 1964), which differs markedly from that

above the Luscar Thrust. The apical angle of the anticlinorium is 90° and the axial surface is vertical whereas the apical angle of the flat-bottomed syncline is 140° .

The lack of longitudinal structural continuity is well illustrated by the F-F' section (fig 17d). It can be seen that the flat-bottomed syncline becomes runnel-shaped to the northwest and also that a deep syncline develops just northeast of the anticlinorial axial surface. The structures are apparent in domains 26 and 28 respectively (appendices 5-26 and 5-28) where 2 possible paths for the coal can be traced. In both cases the deeper syncline can be considered as being in the foreground (to the northwest) whilst the flat-bottomed structure is in the background.

F. Blackstone Detachment Zone

The style of deformation in the Cardium is quite different from that of the Lower Cretaceous strata. The Cardium has been cut by major thrust faults and both the Cardium and the faults have been folded giving rise to smooth, open to gentle, upright folds. This implies that the tight folds in the Lower Cretaceous strata die out in the Blackstone so that the Blackstone is a zone of disharmony or detachment, the beds above and below deforming differently.

This detachment is borne out by the complex deformation within the Blackstone as shown on the diagrammatic section (fig 14). This deformation is also apparent on a large scale

as can be seen from the dramatic changes in thickness of the Blackstone (fig 18). The Blackstone Formation is approximately 500 m (1600 ft) thick on the limbs (fig 17b), which approximates the true thickness, but is greatly thickened in the cores of anticlines and synclines.

A 3.7 km (2.3 mi) section through the Blackstone is almost continuously exposed in the east bank of the McLeod River and adjacent to the railway (fig 14). Many of the mesoscopic structures seen in this section, particularly in the more competent Sunkay Member, are analogous to the large scale structures throughout the area. The vergent folding style is well illustrated by siltstone bands at 3360 m and 3490 m (plate IVb) where both limbs and the axial surface dip to the southwest. The fold at 3360 m (plate Vb) contains an 'out of the syncline' thrust (Dahlstrom, 1970) that becomes a forelimb thrust as it migrates up section. Between 3000 and 3200 m the Upper Sunkay Member is deformed by kink folds with southwesterly dipping axial surfaces.

At least one thrust fault, presumably dipping northeast, must exist in the last 300 m since the fish-scales sandstone is duplicated, outcropping at 3460 m and 3620 m. A low-angle thrust fault is very well exposed in the almost horizontal beds at 1900 m (plate Va) making an angle of 30° with bedding. Furthermore, a thick zone of small thrusts is exposed opposite Leyland Railway Station at 2100 m. This thrust zone would have gone unrecognized and marked as uniformly dipping beds, but for the presence of a

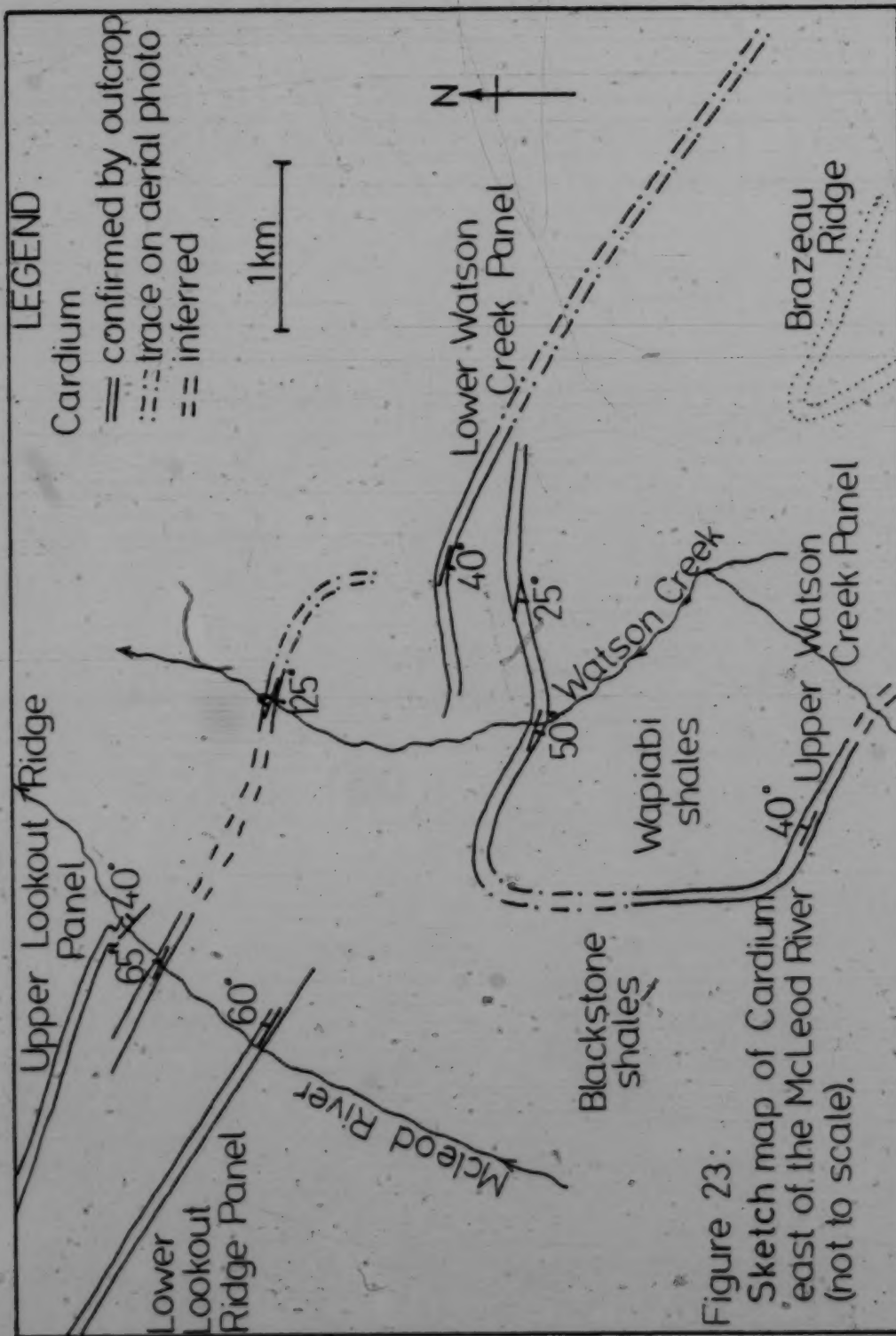
thin concretionary marker horizon. It is possible and indeed likely that such thrusting is common, but unseen when no marker horizons are present.

In the first kilometre or so the folding tends towards isoclinal and the axial surfaces are very difficult to detect. The situation is further complicated by the presence of numerous faults of unknown displacement. The upper 40 m of the Opabin Member contains 3 sandstone bands up to 2 m thick and deforms as if part of the overlying Cardium Formation. Elsewhere in the area exposures of Blackstone Formation are very poor, though a synclinal structure is detectable in Domain 34 (appendix 5-34) corresponding to the syncline in the overlying Cardium.

The Blackstone Formation is complexly deformed, sometimes so much so that it was not possible to unravel the structure. Elsewhere the mesoscopic structures were typical of those seen throughout the area on a larger scale. Many folds and faults have almost certainly gone undetected in this contorted detachment zone.

G. Cardium Structure

The Cardium Formation is more simply folded than the Lower Cretaceous strata and is cut by 3 major thrust faults, the Watson Creek, Fidler and Lookout Thrusts. These give rise to 4 separate Cardium panels, namely the Upper Lookout Ridge, Lower Lookout Ridge, Upper Watson Creek and Lower Watson Creek Panels (figs 18 and 23). The structure of the



Cardium stands out very clearly on aerial photos since its sandstones form prominent ridges between the recessive Blackstone and Wapiabi shales and siltstones. On these ridges the Ram and Sturrock members of the Cardium Formation and the Opabin Member of the Blackstone Formation are often well exposed and form an easily recognizable sequence.

Upper Lookout Ridge Panel

The Upper Lookout Ridge Panel is well exposed along the crest of Lookout Ridge, which is named after the now abandoned Fire Lookout Tower (fig 16). The panel terminates against the Lookout Thrust, approximately 1 km to the northwest of the tower site and is particularly well exposed along the McLeod River and Lower Luscar Creek where it has been duplicated by a small fault. The lack of exposure between the McLeod River and Watson Creek is attributed to the preglacial McLeod River apparently having swung east of its present position to beyond where the railway is today. The Cardium in this panel is overturned along Watson Creek and has been mapped to the east from aerial photos (fig 23) where it is truncated by the Fidler Thrust.

The panel generally strikes northwest, faces northeast and dips at 60°-90° northeast over much of its length. Near its western end the panel is involved in a prominent anticline-syncline pair whose fold axis has an orientation of 118 16. Since these folds are continuous with those in the Lower Lookout Ridge Panel the axial planes have an approximate orientation of 30 90. Little is known about the

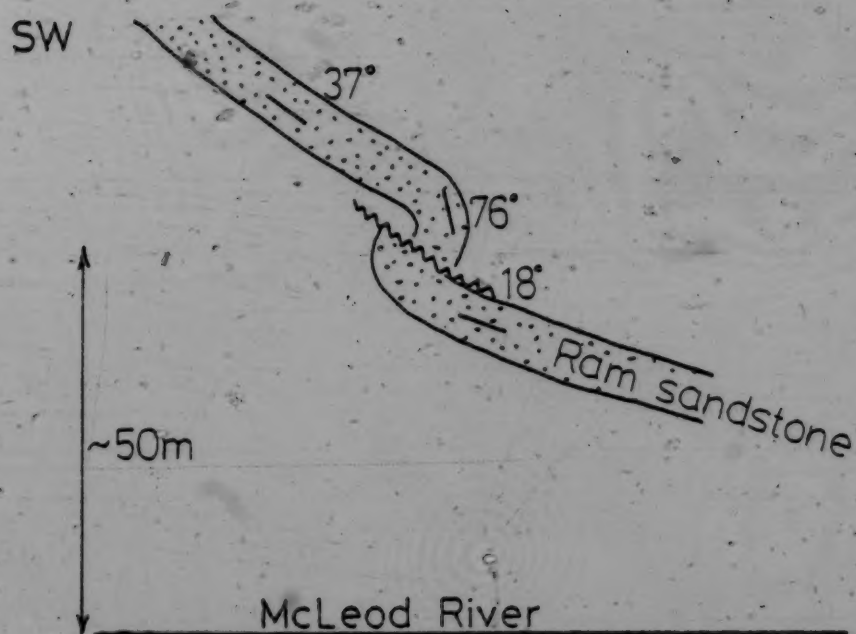
poorly exposed small fold pair 2 km southeast of the Fire Lookout Tower. The small fault cutting the panel along the McLeod River is a steep southwest dipping contraction fault whose sense of rotation, viewed from the northwest, is clockwise. A small fold exposed in the panel adjacent to the contraction fault shows the more usual sense of vergence (fig 24a).

Lower Lookout Ridge Panel

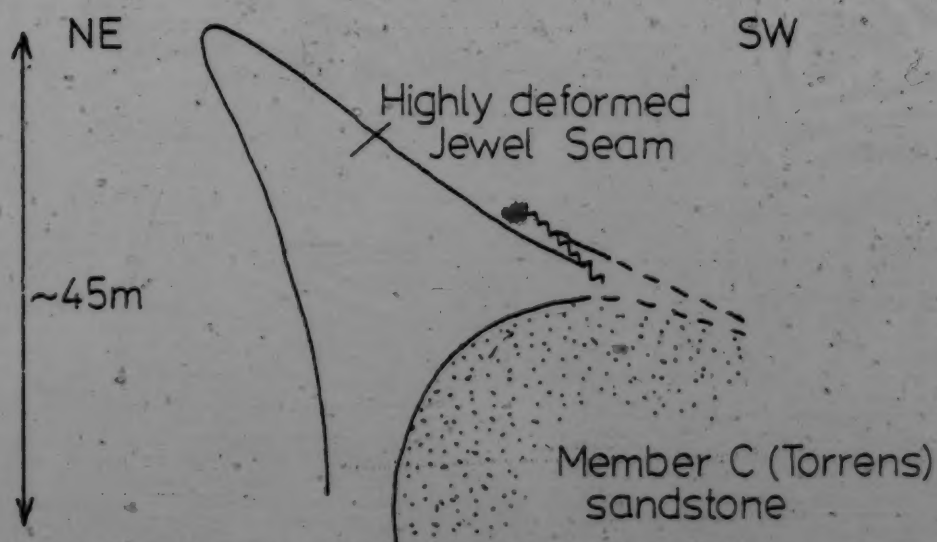
The Lower Lookout Ridge Panel of Cardium sandstone is well exposed along the southwest slopes of the Lookout Ridge and continues to the northwest beyond the area mapped. The easternmost exposures occur just southeast of the McLeod River. The failure of this panel to crop out by Watson Creek suggests that it is truncated by the Lookout Thrust a short distance east of the McLeod River. This panel is subparallel to the upper Lookout Ridge panel, but consistently dips at approximately 60° to the northeast. The western anticline-syncline pair has the same orientation and shape as that of the upper panel and is continuous with it.

Lookout Thrust

The Lookout Thrust lies between the above described panels and is subparallel to them. Since it cuts the lower panel just east of the McLeod River and yet is immediately above it in the anticline-syncline pair the thrust must remain very close to the top of this panel. This implies that the thrust cuts up section in the upper panel between the small fold pair and the panel termination (fig 18).



a) Mesoscopic fold and northeast dipping thrust by the McLeod River 5km north of Cadomin.



b) Differing folding styles in coal and sandstone in the easternmost pit east of the McLeod River.

Figure 24: Field sketches

Furthermore, the thrust must dip down to the northeast and be folded around the anticline-syncline pair. This style of folded thrust is well known along strike to the southwest, between the Pembina and Brazeau Rivers (Hake et al , 1942).

Lower Watson Creek Panel

Cardium strata near the western end of the Lower Watson Creek Panel have an orientation of approximately 200 40 whereas to the southeast they form a prominent ridge with a bearing of about 120°. The panel is underlain by the southwest dipping Fidler Thrust, named after the nearby station, which cuts the Cardium in the footwall 1 km east of Watson Creek and in the hanging wall some 4 km to the southeast. Its displacement is unknown, but may be considerable.

Upper Watson Creek Panel

The synclinal Upper Watson Creek Panel terminates against the Watson Creek Thrust in the north, but the southern limb continues out of the mapping area to the southeast. The dips are everywhere fairly shallow, ranging from 20°-65° and the syncline has a fold axis orientation of 115 5. The structure in the southern limb near the hinge may be more complex than is indicated and may involve duplication of the Cardium Formation. The panel is underlain by the Watson Creek Thrust which cuts the Cardium in the footwall just east of Watson Creek and in the hanging wall, 2 km to the southeast. Its displacement is probably in the order of 500 m.

V. DISCUSSION

In drawing up a kinematic model depicting the structural history of the area the author regards the following observations as significant.

- a. The two large folds in the Lower Cretaceous strata extend upwards, though highly modified, into the Upper Cretaceous Cardium Formation.
- b. At least one of the faults offsetting the Cardium is folded along with this formation.
- c. Both the Luscar Thrust and the small thrusts on the Luscar Anticlinorium have been folded.
- d. The Blackstone Formation has acted as a zone of detachment.
- e. The parasitic folds in the hanging wall of the Luscar Thrust are much tighter and less upright than those of the footwall. Furthermore, whereas the Mountain Park Formation exhibits round, concentric, parasitic folds in the hanging wall, the strata of Luscar Members C and D are tightly to isoclinally folded and the strata beneath the Member B (Moosebar) shales do not appear to be involved in any significant small scale folding.
- f. From southwest to northeast the Luscar Thrust parallels the Moosebar shales, cuts up section at a high angle and then parallels bedding near the base of the Blackstone shale.
- g. The folding style is strongly vergent close to the

Nikanassin Range, but is more upright to the northeast.

These observations lead the author to propose the following 4-stage kinematic model:

1. Decollement along the Blackstone detachment zone took place whilst the underlying strata were still horizontal. The Lookout, Watson Creek and possibly the Fidler Thrusts are examples of splays from this zone that initially dipped gently southwest (fig 25a). According to this interpretation much of the shortening associated with these thrusts is unrelated to the shortening in the underlying Lower Cretaceous. This notion agrees well with the proposal of Charlesworth and Kilby (in press) that a zone of decollement is present in the Blackstone Formation of the Foothills northeast of the Nikanassin Range and that it was active at the same time as thrusts cutting the Lower Cretaceous southwest of the Nikanassin Range. Furthermore, it was active before movement took place on such faults as the Nikanassin and Folding Mountain Thrusts. The exact location of this zone of decollement in the Blackstone shale is unknown, but its trace must enter the area east-southeast of Cadomin and, if Charlesworth and Kilby's estimate of 15 km displacement is correct, leave it northeast of the Gregg River, i.e., the zone must underlie much of the Foothills to the northeast.
2. Folding of the ancestral Nikanassin Range

anticline-syncline pair, the syncline being the precursor to the Cadomin synclinorium (fig 25b). Detachment and gravity sliding of the post-Moosebar strata on the northeast limb of the ancestral Nikanassin Range anticline gave rise to the parasitic concentric folds in the thick, massive Mountain Park sandstones with their associated detachment in the Moosebar shales (fig 25c). This explains the rapid lateral variation in parasitic fold style, the unfolded nature of the pre-Moosebar shales and the absence of similar folds southwest of the Nikanassin Range.

3. Continued movement along the Moosebar detachment zone eventually breaks through the post-Moosebar strata to the Blackstone shales as the Luscar Thrust. The small faults cutting the Jewel Seam in the Luscar anticlinorium may have developed at this time, but may also have been formed during earlier regional compression. Continued folding of the ancestral Nikanassin Range fold pair caused the Nikanassin Thrust to break through the overlying strata (fig 25c and d).
4. Development of the Luscar Anticlinorium in both Lower and Upper Cretaceous strata (fig 25e). The contraction fault in the Cardium probably developed at this stage. It is possible that the Fidler Thrust also developed at this time rather than being early formed since its geometry is somewhat obscure. The Folding Mountain Thrust probably terminates in Nikanassin strata in the

northeast corner of the map area, but it may be related to the folding of the Luscar Anticlinorium in the same way that the Luscar Thrust is related to folding in its hanging wall.

VI. ECONOMIC IMPLICATIONS

By the use of numerical computer-based techniques it has been possible to define the structure of the coal bearing strata and hence the location of the coal seams. However, there is a lack of data for the Jewel Seam immediately northwest of Cadomin and beneath the McLeod River. It was previously demonstrated that the structure in the southwest of the area can be used as a guide to the structure to the northeast. Since the domains adjacent to this 'barren' area plunge down to the northeast (fig 7) it is likely that the top of the Mountain Park Formation is never far below the surface. Thus in the cores of anticlines the coal may be as shallow as 460m (1500 ft) and certainly between 460 m and 760 m (1500-2500 ft). Since it is currently feasible to mine coal underground to depths of 600 m (2000 ft) some of this coal may well be economical.

VII. CONCLUSIONS

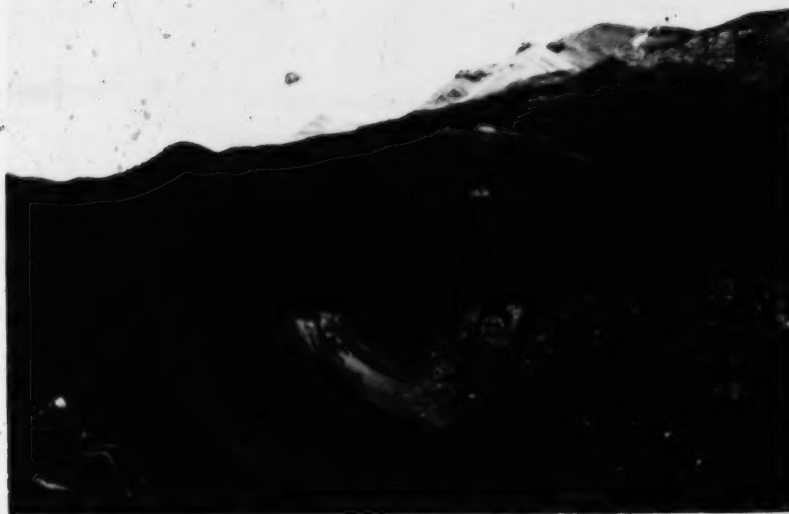
In accomplishing the objectives of this study it is hoped that the pertinence of numerical computer-based techniques to analyze structure has been demonstrated. The structure of the area was analyzed and interpreted and the 4 ancillary objectives have all been realized, namely, (1) A detailed geological map and cross-sections were drawn up, (2) A detailed stratigraphic section through the Luscar Formation was measured and interpreted, (3) Computer techniques were modified and developed to analyze large quantities of borehole data and (4) The structure of the Luscar Formation was related to that of the surrounding beds.

The stratigraphic section has been lithologically correlated with other sections throughout the central Albertan Foothills and the coal seams have been shown to be considerably more extensive than was previously thought. The author's structural interpretation is radically different from that of previous workers. The number of thrust faults compared with that of MacKay has been greatly reduced and those present have been found to be folded, in places dipping down to the northeast. A zone of detachment in the Blackstone Formation was inferred, the detachment having initiated southwest of the Nikanassin Range and continuing out of the area to the northeast.

The recognition of folded thrust-faults will most certainly be important in future exploration in the foothills, down-plunge projections being the tool with which

they can be defined. The through-going zone of detachment in the Blackstone Formation has important implications for structural interpretation in the outer foothills under which it must continue, undoubtedly with splays coming off it cutting the overlying strata.

PLATE I



a) Looking towards the southeast portion of the map area showing the line of cavings, Jewel Seam (J), Torrens sandstone (T), Cadomin conglomerate (G) and Palliser limestone (P).



b) Looking southeast and down plunge in the 50A3 pit where the Jewel Seam (J), above the Torrens sandstone (T), has been mined out. The pit wall is 52 m (170 ft.) high.

PLATE II



a) Looking southeast at overturned Cadomin conglomerate (G) in the Inland Cement Quarry, stratigraphically overlying faulted Nikanassin sandstone (N). Trail bike for scale.



b) Looking southeast across the McLeod River at the upper 96m (312 ft.) of the Gladstone Formation overlain by the Moosebar shales (M). Anticlinal axis at 'A'.

PLATE III



a) Looking southeast at 51B2 pit displaying Torrens sandstone (T), Jewel Seam (J), Ryder Seam (R) and the base of the Mountain Park Formation (M). The pit wall is 100m (325 ft.) high.



b) Looking southeast in 51C3 pit at a northeast dipping thrust (F-F) offsetting the Ryder Seam (R). The pit wall is 30m (100 ft.) high.

PLATE IV



a) Looking southeast at an anticlinal axis in the Gladstone Formation (position 'A' on plate 4). The outcrop is 9m (29 ft.) high.

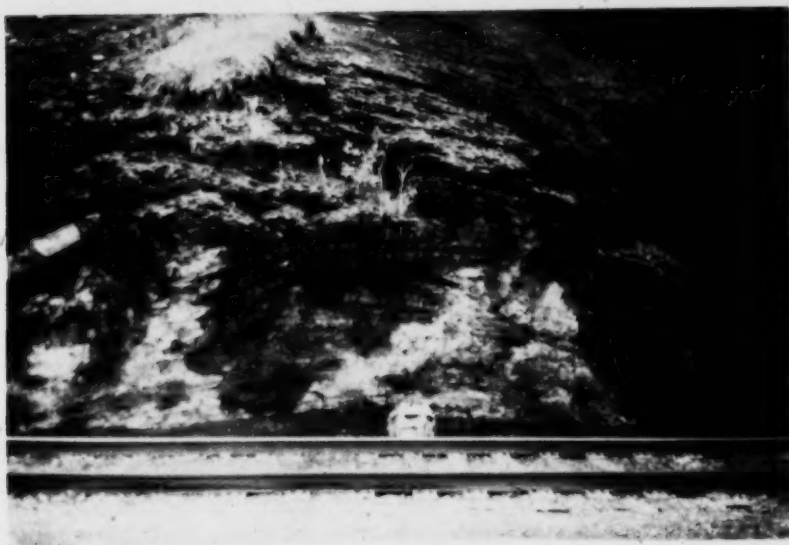


b) Looking southeast at an anticline-syncline pair in the Sunkay Member of the Blackstone Formation. The outcrop is 18m (59 ft.) high.

PLATE V



a) Looking southeast at a low angle thrust fault (F-F) in the Vimy Member of the Blackstone Formation, opposite Leyland Station. The outcrop is 20m (65 ft.) high.



b) Looking southeast at an "Out of the Syncline" thrust (F-F) within a fold, similar to that of Plate IV b, in the Sunkay Member of the Blackstone Formation. Rucksack for scale.

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APPENDIX 1a

FIELD DATA SHEET

Station No.		Date	
Formation & Member			
Distance Above Formation Base			
Station Coordinates		X	
		Y	
		Z	
Station Position Reliability			
Bedding Linears		Mesoscopic Folds	
Faults		Joints	
Lithology		Fossils	
Gen Obs.		Photos	
Bedding Orientations			

APPENDIX 1b

RAWPLANE and RAWFOLD

The files RAWPLANE and RAWFOLD have exactly the same format, the column in the file corresponding to the box on the field data sheet:-

Column

1-4 Outcrop number

5-6 Day of month

7 Month

8 Year

9-10 Digits 0-9 representing formation and member

11-14 Distance above formation base (if known) in feet.

15-19 Eastings (in feet)

20-24 Northings (in feet)

25-29 Elevation (in feet)

30 Reliability of location of the outcrop on the map using a scale of 1-3, 1 being reliable, 3 being unreliable.

31-38 A '1' is placed in this column if the relevant feature on the data sheet was seen at the outcrop, otherwise a '0' is recorded.

39-79 Up to 6 orientations of bedding (measured in grads) in terms of dip direction and dip, with a space between each reading.

80 A '1' was placed in this column if additional data were recorded in the field notebook.

APPENDIX 1c

PLANE

The format of the file PLANE is:-

Column

- 1 Alphabetic code for stratigraphic position
- 2-16 Outcrops coordinates as in RAWPLANE.
- 18-23 Mean bedding orientation
- 26 Number of the bedding measurements
- 29-36 The statistic 'K' that measures the scatter of the repeated measurements about the mean bedding orientation
- 39-44 First bedding orientation at outcrop (random bedding orientation)
- 47 '1' if additional data recorded
- 50 Reliability of outcrop location (RAWPLANE column 30)
- 53-60 As columns 31-38 in RAWPLANE
- 63-66 Distance above formation base (in feet)
- 71-74 Outcrop number
- 77-78 Digits 0-9 representing formation and member

APPENDIX 1d

FOLD

The format of the file FOLD is:-

Column

2-16 Outcrop coordinates as in RAWFOLD

18-23 Orientation of mesoscopic fold axis

80 A '3' is recorded in this column to indicate mesoscopic
fold data

APPENDIX 2a

SURVEY SYSTEM USED BY CARDINAL RIVER COALS LTD.

The positions of drill hole collars on the Cardinal River Coal property are described on the Drill Hole Summary Sheets with reference to 4 northwesterly trending baselines and 18 northeasterly trending section lines. From southwest to northeast the baselines are 50A, 50B, 51B and 51C, and from southeast to northwest the section lines are T, U, V, W, X, Y, Z, A, B...P. Although the section lines along a baseline are each 3000 ft apart and normal to the associated baseline, the baselines are irregularly oriented and irregularly spaced. The relationship between each baseline and its associated section lines on the one hand and an east-west north-south rectangular grid system on the other hand is described below. For the purposes of describing this relationship the property is divided into the following baseline areas: (1) 50-A, (2) 50-B southeast, (3) 50-B northwest, (4) 51-B, (5) 51-C southeast and (6) 51-C northwest. The point whose grid coordinates are 100,000E and 100,000N is at the NE corner of Section 21, Township 47, Range 24, W of the 5th meridian. 50000 has been subtracted from both northing and easting coordinates for the purposes of this study.

1. 50-A. The 50-A baseline has a bearing of $229^{\circ}55'24''$. The associated section lines W, X, Y, Z, A...F are such that the grid coordinates of the point where the W section

line crosses the baseline are 80,332.01N and 122,714.66E.

2. 50B southeast. Where section lines A-C cross the 50-B baseline, it has a bearing of 300°. The point where the A section line crosses the baseline has grid coordinates of 91,468.24N and 115,281.34E.
3. 50-B northwest. Where section lines L-N cross the 50-B baseline, it has a bearing of 299°55'24". The point where the L section line crosses the baseline has grid coordinates of 107,940.13N and 86,692.55E.
4. 51-B. The 51-B baseline has a bearing of 299°57'14". The associated section lines A-F are such that the point where the A section line crosses the baseline has grid coordinates of 94,871.65N and 117,244.58E.
5. 51-C southeast. The 51-C baseline has a bearing of 299°55'25". Section lines D-K are such that the point on the baseline 2000 ft northwest of the D intersection has grid coordinates of 103,205.92N and 109,351.56E.
6. 51-C northwest. For section lines L and M the 51-C baseline has the same bearing, but is offset 2000 ft to the southwest. The point where the L section line crosses the baseline has grid coordinates of 112,447.2N and 89,286.54E.

APPENDIX 2b

DATA AVAILABLE FROM THE SUMMARY SHEETS

1. Base Line. The base line used to define the position of the drill hole (see below) was obtained from the space labelled "Project" at the top left hand corner of each sheet or from the space labelled "Comments" at the right hand edge of each sheet.
2. Year. The year of drilling was obtained from the space labelled "Year" at the top of each sheet or from the space labelled "Date" (see below).
3. Hole Number.
4. Inclination of Drill Hole.
5. Azimuth of Drill Hole.
6. Coordinates.
 - a. North South (see below)
 - b. East West (see below)
7. Collar Elevation.
8. Total Depth.
9. Electric Logs.
 - a. Natural Gamma
 - b. Density
 - c. Resistivity
 - d. Date
 - e. Depth
10. Driller's Log Availability.

11. Overburden Depth.
12. Water Table Depth.
13. Seam Data:
 - a. Identity of Seam
 - b. Depth to top of seam or coal interval within seam
 - c. Depth to bottom of seam or coal interval within seam
 - d. Thickness of coal seam or interval.
14. Sample Availability.
15. Elevations.
 - a. Hole bottom
 - b. Top of seam or coal interval
 - c. Bottom of seam or coal interval
16. Rig Type.
17. Fluid Type.
18. Comments.

Data contained on the Drill Hole Summary Sheets concerning the type of drilling rig and drilling fluid used (16 and 17) were not computerized; neither were the thicknesses of seams (13d), the elevations of the bottoms of holes, the tops of seams or the bottoms of seams (15).

Three files called HOLE, SEAM and COMMENT were built using data from the Summary Sheets. Each line in a file contains data from one hole and includes the Hole Number (3) on which the files were cross-referenced.

Holes 29A, 30A, 332A, 745A, 2167A, 2167B, 2195A, 2195B, 2214A, 2214B, 2404A, 2404B were renumbered as 3000, 3001, 3002, 3003, 2167, 3004, 2195, 3005, 3006, 2214, 2404, 3007,

respectively. There are no data in the Summary Sheets for the following holes: 944, 1036-9, 1044, 1386, 1697-1943, 2190, 2265, 2432, 2434-7, 2443, 2455, 2460-1, 2463, 2482, 2627 and 2636. Data such as the identity of the base line, drill hole inclination, drill hole azimuth, coordinates and the collar elevation were missing from the following holes which have been omitted from the computer files: 14, 21, 29-36, 72, 186, 197-8, 200, 224, 287, 376, 482, 600, 701, 713-4, 717-9, 723, 729, 741-4, 746-51, 754-5, 767, 769, 930, 1000-5, 1016, 1101, 1110, 1143, 1153-9, 1239, 1280, 1361, 1372, 1401-5, 1413-5, 1437-8, 1452, 1486, 1696, 2007, 2043, 2058, 2113, 2119, 2126, 2133, 2148-9, 2164, 2190, 2247, 2251, 2264, 2272, 2277, 2468, 2486, 2606, 2643, 2678-9, 2695-6, 2698, 2701-10, 2712, 2714, 2732, 3000 and 3001.

APPENDIX 2c

HOLE

The format of the file HOLE is:-

Column

1-3 Baseline. 50A, 50B, 51B or 51C.

4-5 Year. 68, 69...

6-9 Hole Number.

10-11 Inclination. The inclination of the hole in degrees (0-90).

12-14 Azimuth. The azimuth of the hole in degrees (0-359).

This column is blank when the inclination is 90°.

15 Section Line. Each entry consists of a single letter (W, X, Y, Z, A, B...N) obtained from the North-South Coordinates entry in the Drill Hole Summary Sheets.

16-19 Baseline Increment. The distance in feet that the hole is northwest of the above section line, measured parallel to the baseline, was also obtained from the North-South Coordinates entry.

20 Side. Each entry consists of a single letter (L, R) indicating the direction that the hole is from the baseline, L being southwest and R northeast. It was obtained from the East West Coordinates entry on the Summary Sheets.

21-24 Section Line Coordinate. The distance that the hole is from the baseline, measured parallel to the section line, was also obtained from the East West Coordinates

entry.

25-28 Collar Elevation.

29-31 Total Depth.

32-34 Natural Gamma, Density and Resistivity Logs. If a natural gamma, density or resistivity log was available for a hole, 1 was placed in columns 32, 33 or 34, respectively.

35-38 Date. The data on which the E-logs were run for a hole was entered in columns 35-38, the first two digits specifying the month and the second two the day.

39-41 Electric Log Depth.

42 Driller's Log. If a driller's log was available for a hole, 1 was placed in this column.

43-44 Overburden Depth.

45-47 Water Table Depth.

APPENDIX 2d

SEAM

Whereas every hole included in the Drill Hole Summary Sheets has an entry in the file HOLE, only those holes that encountered coal have one or more entries in the file SEAM, the number of entries equalling the number of seams or parts of a seam between shale splits. The format of the file SEAM is:-

Column

1-4 Hole Number. This entry is the same as in columns 6-9 of the file "Hole".

5 Identity of Seam. In some cases, the letters J or R in the sixteenth column headed "Seam Data-No." of the Summary Sheets indicate that the coal associated with the entry has been identified as being or belonging to the Jewel or Ryder seams.

6-10 Depth Top. The depth in feet to the nearest tenth of a foot to the top of the coal interval was obtained from the seventeenth column of the Summary Sheets.

11-15 Depth Bottom. The depth in feet to the nearest tenth of a foot to the bottom of the coal interval was obtained from the eighteenth column of the Summary Sheets.

16-17 Number of Entry. Each hole that encountered coal has one or more entries, each entry corresponding to a certain coal interval. These are numbered consecutively

from the top downwards.

18-20 Samples. If a core, SW or Chip sample of a coal interval was taken, an "X" was placed in columns 18-20, respectively.

APPENDIX 2e

COMMENT

Only those holes with comments available in the Drill Hole Summary Sheets have entries in the file COMMENT. The format of the file COMMENT is:-

Column

1-4 Hole Number. This entry is the same as in columns 6-9 of the file "Hole".

5-79 Comments. The comments are in free format and can contain both numerical and alphabetical characters.

APPENDIX 3a

CONVERT

Source listing of the program CONVERT (see accompanying diagrams and fig 3 for explanation).

Run commands

\$RUN CONVERT 1=HOLE 2=SEAM 3=CARDINAL 4=COLLARS

```

1      C      This program converts the co-ordinates of the borehole collars from
2      C      the mine grid system to eastings, northings and elevation in feet and
3      C      outputs them with the appropriate borehole number. The borehole collar
4      C      co-ordinates, azimuth and inclination together with depth down the
5      C      borehole to the coal seams are used to calculate the eastings, northings
6      C      and elevation of each intersection which are output in a second
7      C      file with the appropriate borehole number and seam intersection number
8      C
9      C      The input data comprises the section lines W-Z and A-N (SECT), the
10     C      baseline side:-that is left or right (SIDET), the baselines SOA, SOB,
11     C      SIB and SIC (BSLT), the perpendicular distance in feet from the origin
12     C      to the W section line (ICB), the bearing in degrees of the baseline
13     C      from north (TH), and the eastings (ORE) and northings (ORN) of the
14     C      local origin, both less 50000.
15     C
16     C      DIMENSION SECT(18),BSLT(4),ICB(6),TH(6),ORE(6),ORN(6)
17     C      DATA SECT/'W','X','Y','Z','A','B','C','D','E','F','G',
18     C      'H','I','J','K','L','M','N',SIDET/'L',BSLT/'SOA','SOB',
19     C      'SIB','SIC'/
20     C      DATA ICB/0,12000,12000,23000,45000,45000/
21     C      DATA TH/60.0708333,60.0,60.04611111,60.0738889,60.0766667,
22     C      60.0763889/
23     C      DATA ORE/72714.66,65281.34,67244.58,59351.56,36692.55,
24     C      39286.54/
25     C      DATA ORN/30332.01,41468.24,44871.65,53205.92,57940.13,
26     C      62447.2/
27     C      IREAD=1
28     C      RAD=3.14159265/180.0
29     C
30     C      PART 1 :-Two "do loops" determine firstly the section line used to
31     C      reference the borehole and the perpendicular distance of that line
32     C      from the W section line and secondly, the baseline used to reference
33     C      the borehole (1,2,3 or 4). An error message is printed if the data
34     C      are incorrect.
35     C
36     C      10 READ(1,20,END=700)BSL, IDHOLE, INCL, IAZ, SEC, INCRY, SIDE, IXCRD, IELEV
37     C      20 FORMAT(A3,2X,I4,I2,I3,A1,I4,A1,I4,I4)
38     C      DO 40 J=1,18
39     C      IF(SEC-SECT(J))40,30,40
40     C      IYSEC=(J-1)*3000
41     C      GOTO 60
42     C      CONTINUE
43     C      WRITE(6,50)IDHOLE
44     C      50 FORMAT(' DATA ERROR, HOLE #',I4)
45     C      GOTO 10
46     C      DO 80 J=1,4
47     C      IF(BSL-BSLT(J))80,70,80
48     C      IB=J
49     C      GOTO 90
50     C      CONTINUE
51     C      WRITE(6,50)IDHOLE
52     C      GOTO 10
53     C

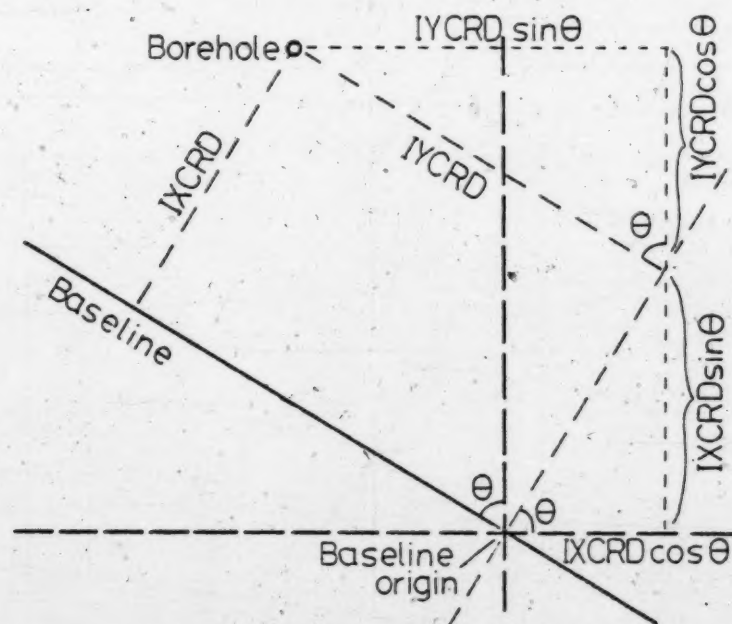
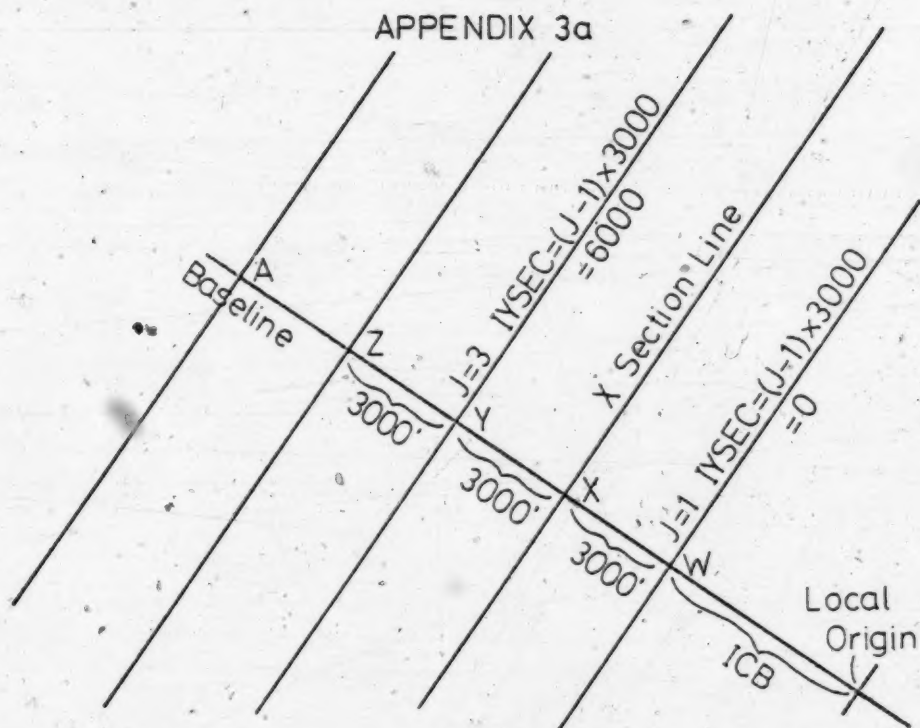
```

```

54 c The 508 and 51C baselines are divided up into N.W. and S.E. The
55 c distance from the origin to the borehole collar measured parallel to
56 c the baseline in question is calculated (IYCRD). The perpendicular
57 c distance from the baseline to the borehole (IXCRD), read from the
58 c initial data, is made negative if the borehole is left of the baseline.
59 c The eastings and northings are calculated with respect to local origin
60 c and then for the map origin. These are truncated to 5 digits (IFE and
61 c IFN) to be output.
62 c
63 90 IF(IB.EQ.2.AND.IYSEC.GT.45000)IB=5
64 IF(IB.EQ.4.AND.IYSEC.GT.45000)IB=6
65 IYCRD=IYSEC+INCRY-ICB(IB)
66 THETA=TH(IB)*RAD
67 IF(SIDE.EQ.SIDET)IXCRD=-IXCRD
68 PEAST=COS(THETA)*IXCRD-SIN(THETA)*IYCRD
69 PNRTN=SIN(THETA)*IXCRD+COS(THETA)*IYCRD
70 FEAST=ORE(IB)+PEAST
71 FNRTN=ORN(IB)+PNRTN
72 IFE=FEAST+0.5
73 IFN=FNRTN+0.5
74 WRITE(4,100)IFE,IFN,IELEV,IDHOLE
75 100 FORMAT(1X,4I5)
76 c
77 c PART 2
78 c The trigonometric functions SC and CC are calculated in order to
79 c calculate eastings and northings of intersections using azimuth (AZ)
80 c and inclination (ANCL). Data are read from the input file and the
81 c borehole numbers matched with those of the first input file. The
82 c eastings, northings and elevation of the intersections are calculated
83 c and rounded to the nearest whole foot, as are those of the bottom
84 c of the hole.
85 c
86 AZ=IAZ*RAD
87 ANCL=INCL*RAD
88 SC=SIN(AZ)*COS(ANCL)
89 CC=COS(AZ)*COS(ANCL)
90 200 IF(IREAD.EQ.1)READ(2,300,END=700)IDHS,NAME,DEP1,DEP2
91 IREAD=1
92 300 FORMAT(14,A1,2F5.1)
93 IF(IDHOLE-IDHS)400,500,200
94 400 IREAD=0
95 GOTO 10
96 500 CONTINUE
97 INTE1=FEAST+DEP1*SC+0.5
98 INTN1=FNRTN+DEP1*CC+0.5
99 INTEL1=IELEV-DEP1*SIN(ANCL)+0.5
100 WRITE(3,600)NAME,INTE1,INTN1,INTEL1,IDHOLE
101 600 FORMAT(A1,3I5,8X,14)
102 INTE1=FEAST+DEP2*SC+0.5
103 INTN1=FNRTN+DEP2*CC+0.5
104 INTEL1=IELEV-DEP2*SIN(ANCL)+0.5
105 WRITE(3,600)NAME,INTE1,INTN1,INTEL1,IDHOLE
106 GOTO 200
107 700 STOP
108 END

```

APPENDIX 3a



$$\begin{aligned}\text{Easting} &= \text{IXCRD} \cos \theta - \text{IYCRD} \sin \theta \\ \text{Northing} &= \text{IXCRD} \sin \theta + \text{IYCRD} \cos \theta\end{aligned}$$

APPENDIX 3b

CAR2DIT

Source listing of the program CAR2DIT

Run commands

\$RUN CAR2DIT 1=CARDINAL2 2=JEWEL2

```
1      C      This program edits the input file (in
2      C      the format of CARDINAL) and stores
3      C      alternate lines so that only the top
4      C      of the interval is kept and the base
5      C      discarded. The program also adds 2000
6      C      to the hole number.
7      C
8      INTEGER I,I1,I2,I3,I4,I5,I6
9      DATA I/1/
10     5      READ(1,10,END=100)I1,I2,I3,I4
11     10     FORMAT(1X,(3I5),8X,I4)
12           I6=I4+2000
13           WRITE(2,20)I,I1,I2,I3,I6
14     20     FORMAT(1I,(3I5),54X,I4)
15           READ(1,30,END=100)I5
16     30     FORMAT(24X,I4)
17           IF(I5-I4) 50,5,40
18     40     BACKSPACE 1
19           GOTO 5
20     50     WRITE(2,60)I5
21     60     FORMAT(13H OUT OF ORDER,I4)
22           GOTO 5
23     100    STOP
24           END
```

APPENDIX 3c

FIND

Source listing of the program FIND

Run commands

\$RUN FIND 1=JEWEL2 2=HOLE 3=HOLES 4=-ERROR

```

1      C      This program reads the borehole numbers in
2      C      the 2 input files and compares them. If the
3      C      number occurs in both files it is ignored.
4      C      but if it occurs in the second file only
5      C      that datum line is output. If the number is
6      C      in the first file only an error message is
7      C      output.
8      C
9      5      READ(1,10,END=100) INTJ
10     10     FORMAT(70X,I4)
11     15     READ(2,20,END=100) INTH
12     20     FORMAT(5X,I4)
13           INTH=INTH+2000
14     25     IF(INTH-INTJ) 30,5,40
15     30     BACKSPACE 2
16           READ(2,35)BSL, IDHOLE, INCL, IAZ, SEC, INCRY, SIDE, IXCRD, IELEV, IBOT
17     35     FORMAT(A3,2X,I4,I2,I3,A1,I4,A1,I4,I4,I3)
18           WRITE(3,35)BSL, IDHOLE, INCL, IAZ, SEC, INCRY, SIDE, IXCRD, IELEV, IBOT
19           GOTO 15
20     40     WRITE(4,45) INTJ
21     45     FORMAT(17H DATUM ERROR HOLE,2X,I4)
22           READ(1,10,END=100) INTJ
23           GOTO 25
24     100    STOP
25     END

```

APPENDIX 3d

CON

Source listing of the program CON

Run commands

\$RUN CON 1=HOLES 3=NOCOAL 4=NOCOALB

```

1      C      This program is adapted from CONVERT and
2      C      applies the same logic. The program
3      C      converts the co-ordinates of the borehole
4      C      collars from the mine grid system to
5      C      eastings, northings and elevation in feet
6      C      and outputs them with the appropriate
7      C      hole number. The borehole collar
8      C      co-ordinates, azimuth and inclination are
9      C      used together with the depth of the hole
10     C      bottom to calculate the eastings,
11     C      northings and elevation of the hole
12     C      bottom, output in a second file with the
13     C      hole number.
14     C
15     INTEGER DEP1,NAME
16     DATA NAME/5/
16.5   * IELEV,DEP1
17     DIMENSION SECT(18),BSLT(4),ICB(6),TH(6),ORE(6),ORN(6)
18     DATA SECT/'W','X','Y','Z','A','B','C','D','E','F','G',
19     * 'H','I','J','K','L','M','N'/.SIDET/'L'/.BSLT/'50A','50B',
20     * '51B','51C'/
21     DATA ICB/0,12000,12000,23000,45000,45000/
22     DATA TH/60.0708333,60.0,60.04611111,60.0738889,60.0766667,
23     * 60.0763889/
24     DATA ORE/72714.66,65281.34,67244.58,59351.56,36692.55,
25     * 39286.34/
26     DATA ORN/30332.01,41468.24,44871.65,53205.92,57940.13,
27     * 62447.2/
28     IREAD=1
29     RAD=3.14159265/180.0
30     10  READ(1,20,END=700)BSL,IDHOLE,INCL,IAZ,SEC,INCR,Y,SIDE,IXCRD,
31     * IELEV,DEP1
32     20  FORMAT(A3,2X,I4,I2,I3,A1,I4,A1,I4,I4,I3)
33     IDHOLE=IDHOLE+2000
34     DO 40 J=1,18
35     IF(SEC-SECT(J))40,30,40
36     30  IYSEC=(J-1)*3000
37     GOTO 60
38     40  CONTINUE
39     WRITE(6,50)IDHOLE
40     50  FORMAT(' DATA ERROR, HOLE #',I4)
41     GOTO 10
42     DO 80 J=1,4
43     IF(BSL-BSLT(J))80,70,80
44     70  IB=J
45     GOTO 90
46     80  CONTINUE
47     WRITE(6,50)IDHOLE
48     GOTO 10
49     90  IF(IB.EQ.2.AND.IYSEC.GT.45000)IB=5
50     IF(IB.EQ.4.AND.IYSEC.GT.45000)IB=6
51     IYCRD=IYSEC+INCR-Y-ICB(IB)
52     THETA=TH(IB)*RAD
53     IF(SIDE.EQ.SIDET)IXCRD=-IXCRD
54     PEAST=COS(THETA)*IXCRD-SIN(THETA)*IYCRD
55     PNRTN=SIN(THETA)*IXCRD+COS(THETA)*IYCRD

```

```
56      FEAST=ORE(IB)+PEAST
57      FNRTN=ORN(IB)+PNRTN
58      IFE=FEAST+0.5
59      IFN=FNRTN+0.5
60      WRITE(4,100)NAME,IFE,IFN,IELEV,IDHOLE
61      100  FORMAT(I1,3I5,54X,I4)
62      AZ=IAZ*RAD
63      ANCL=INCL*RAD
64      SC=SIN(AZ)*COS(ANCL)
65      CC=COS(AZ)*COS(ANCL)
66      IF(DEP1.LT.NAME)GOTO 10
67      INTE1=FEAST+DEP1*SC+0.5
68      INTN1=FNRTN+DEP1*CC+0.5
69      INTEL1=IELEV-DEP1*SIN(ANCL)+0.5
70      WRITE(3,600)NAME,INTE1,INTN1,INTEL1,IDHOLE
71      600  FORMAT(I1,3I5,54X,I4)
72      GOTO 10
73      700  STOP
74      END
```


APPENDIX 3e

ADJUST

Source listing of the program ADJUST

Run commands

\$RUN ADJUST 1=COLLARS 2=COLLAR1

```
1      C      This program rearranges the data to be acceptable to
2      C      the program DRAW and adds 2000 to the borehole number.
3      C
4      INTEGER IN1,IN2,IN3,IN4
5      1      READ(1,100,END=300)IN1,IN2,IN3,IN4
6      100    FORMAT(1X,(3I5),I5)
7      90     CONTINUE
8      IN4=IN4+2000
9      WRITE(2,200,END=300)IN1,IN2,IN3,IN4
10     200    FORMAT(1X,(3I5),53X,I5)
11     GOTO 1
12     300    STOP
13     END
```

APPENDIX 3f

SMED

Source listing of the program SMED

Run commands

\$run SMED 1=SEAM 2=SEAM2

```

1      C      This program edits the input file (SEAM)
2      C      so that only the first intersection with
3      C      the Jewel Seam, labelled with a 'J', or
4      C      with a coal interval greater than 20 feet
5      C      thick is stored for any one hole. Each
6      C      interval in a hole is read to see if a 'J'
7      C      is present and if so the data are stored
8      C      and the next hole tested. If not then the
9      C      interval is tested to see if it is greater
10     C      than 20 (RTEST) and if so it is stored and
11     C      the next hole tested.
12     C
13     REAL R2,R3,RTEST,R
14     INTEGER I1,CHAR,I4,TEST,COUNT
15     DATA TEST/'J'/,RTEST/20.0/
16     COUNT=1
17     5      READ(1,10,END=100)I1,CHAR,R2,R3,I4
18     10     FORMAT(I4,A1,2F5.1,I2)
19     15     IF(COUNT-I1) 20,25,5
20     20     COUNT=COUNT+1
21     GOTO 15
22     25     IF(CHAR.EQ.TEST)GOTO 30
23     R=R3-R2
24     IF(R-RTEST) 5,30,30
25     30     WRITE(2,10)I1,CHAR,R2,R3,I4
26     COUNT=COUNT+1
27     GOTO 5
28     100    STOP
29     END

```

APPENDIX 3g

CARDINAL

The format of the file CARDINAL is:-

Column

1 'J' or 'R' for Jewel or Ryder seam, if identified.

2-16 Coordinates of hole intersection with coal.

25-28 Hole number.

COLLARS

The format of the file COLLARS is:-

Column

2-16 Coordinates of borehole collar.

18-21 Hole number

APPENDIX 4

STATEST

The sequence of events in the source program STATEST is:

CYLTEST and FTEST are run consecutively 3 times; for each half of the domain and then the whole domain respectively. CYLTEST (available in the Department of Geology) uses a domain as input to calculate the number of values, the eigenvalues with associated trends and plunges and the standard deviation. FTEST sorts the output data from CYLTEST placing the minimum eigenvalue and number of readings in one file (-D6) for later use in calculation and all the data in a second file (-D7).

CALC uses the numbers of readings and the minimum eigenvalues in -D6 to calculate the statistics F1 and F for the two halves of the domain and the whole domain respectively (Charlesworth et al, 1976, P.55) F1 and F are placed in the file -D7.

XTEST uses the complete domain as input to calculate the statistic K using the number of readings at each outcrop (r) and the value of 'K' for each outcrop previously calculated by the program MEANS (used to obtain PLANE from RAWPLANE, -see preliminary processing).

MOVE uses the complete domain as input and shifts the random orientation data reading to a position where it can be processed by CYLTEST. The latter is then run using the adjusted domain as input such that the random orientation

reading takes the place of the average reading in the calculation of the minimum eigenvalue, E .

CALCX uses the value of K from XTEST and E from CYLTEST to calculate KxE statistic which is placed in the file -D7.

APPENDIX 4a

FTEST

Source listing of the program FTEST. For run commands see STATEST (fig 5).

```

1      c      The value P is read from the third line
2      c      in the input file and is output, then
3      c      the value E1 is read from the ninth line
4      c      and output. The input file is rewound and
5      c      lines 1-9 are output.
6      c
7      INTEGER IN, IN1, COUNT, P, A, B, C, D, E, F, G, H, I, J, K
8      REAL E1
9      DATA IN/3/, IN1/9/
10     COUNT=1
11     10 IF (COUNT.EQ. IN) GOTO 20
12     READ(1, 200, END=300) A, B, C, D, E, F, G, H, I, J, K
13     COUNT=COUNT+1
14     GOTO 10
15     20 READ(1, 50) P
16     50 FORMAT(4X, I2)
17     COUNT=COUNT+1
18     60 IF (COUNT.EQ. IN1) GOTO 100
19     READ(1, 200, END=300) A, B, C, D, E, F, G, H, I, J, K
20     COUNT=COUNT+1
21     GOTO 60
22     100 READ(1, 110) E1
23     110 FORMAT(25X, F6.4)
24     WRITE(2, 120) P, E1
25     120 FORMAT(I2, 1X, F6.4)
26     REWIND 1
27     130 READ(1, 200, END=300) A, B, C, D, E, F, G, H, I, J, K
28     WRITE(3, 200, END=300) A, B, C, D, E, F, G, H, I, J, K
29     GOTO 130
30     200 FORMAT(11A4)
31     300 STOP
32     END

```

APPENDIX 4b

CALC

Source listing of the program CALC. For run commands see STATEST (fig 5).

```

1      C      The values P,P1,P2,E,E1 and E2 are read, F1
2      C      and F are calculated from simple equations
3      C      and output.
4      C
5      INTEGER P,P1,P2
6      REAL E1,E2,E,F,F1
7      READ(1,10) P1,E1
8      READ(1,10) P2,E2
9      READ(1,10) P,E
10     FORMAT(I2,1X,F6.4)
11     F1=((FLOAT(P2)-2)*E1)/((FLOAT(P1)-2)*E2)
12     WRITE(2,15)F1
13     15  FORMAT(19H THE VALUE OF F1 IS,F8.4)
14     F=((FLOAT(P)-4)*(E-E1-E2))/(2*(E1+E2))
15     WRITE(2,20) F
16     20  FORMAT(18H THE VALUE OF F IS,F8.4)
17     STOP
18     END

```

APPENDIX 4c

XTEST

Source listing of the program XTEST. For run commands see STATEST (fig 5).

```

1      C      This program reads R1 and K1 for each line
2      C      and sums both R1 and R1/K1. The sum of R1
3      C      is output and also divided by the sum of
4      C      R1/K1 to output K.
5      C
6      REAL KI, K, SUM, TITLE(3)
7      INTEGER RI, R, Q
8      READ(5,2) TITLE
9      2 FORMAT(3A4)
10     WRITE(6,2) TITLE
11     R=0
12     Q=0
13     SUM=0
14     5 READ(5,10,END=100) RI, KI
15     10 FORMAT(25X,I1,2X,F8.2)
16     IF (KI.EQ.0) GOTO5
17     SUM=SUM+RI/KI
18     R=R+RI
19     Q=Q+1
20     GOTO 5
21     100 K=R/SUM
22     WRITE(6,200) Q
23     200 FORMAT(18H NO OF READINGS IS,2X,I2)
24     WRITE(6,250) K
25     250 FORMAT(14H VALUE OF K IS,2X,F10.2)
26     STOP
27     END

```


APPENDIX 4d

MOVE

Source listing of the program MOVE. For run commands see STATEST (fig 5).

```
1      c      .This program shifts part of the data in
2      c      the file 21 spaces to the left.
3      c
4      INTEGER INT, I1, I2, I3, I4, I5
5      READ(1, 4) INT
6      4      FORMAT(I1)
7      WRITE(2, 4) INT
8      5      READ(1, 10, END=100) I1, I2, I3, I4, I5
9      10     FORMAT(1X, (3I5), 22X, (2I3))
10     WRITE(2, 20, END=100) I1, I2, I3, I4, I5
11     20     FORMAT(1X, (3I5), 1X, (2I3))
12     GOTO 5
13     100    STOP
14     END
```

APPENDIX 4e

CALCX

Source listing of the program CALCX. For run commands see STATEST (fig 5).

```
1      C      K1 and E are read, multiplied together
2      C      and output.
3      C
4      REAL E,K1,K
5      READ(1,10) E
6      10    FORMAT(25X,F6.4)
7      READ(2,20) K1
8      20    FORMAT(14X,F10.2)
9      K=E*K1
10     WRITE(3,30) K
11     30    FORMAT(20H THE VALUE OF K*E IS,F12.4)
12     STOP
13     END
```

APPENDIX 5

DOMAIN PROFILES

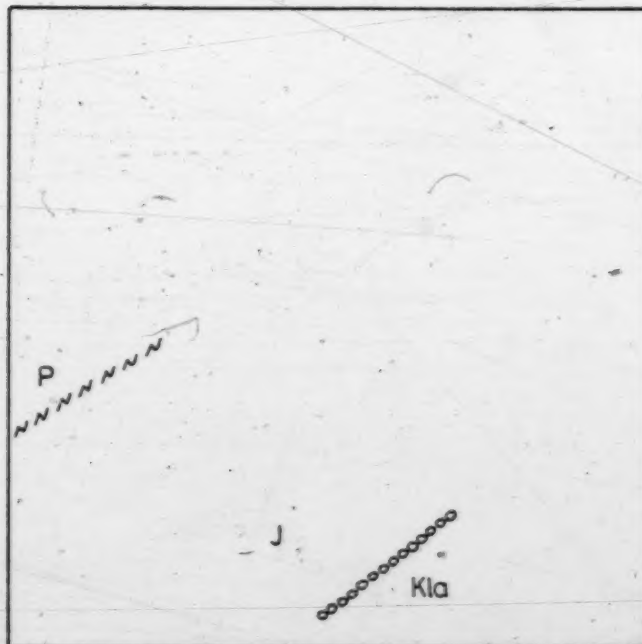
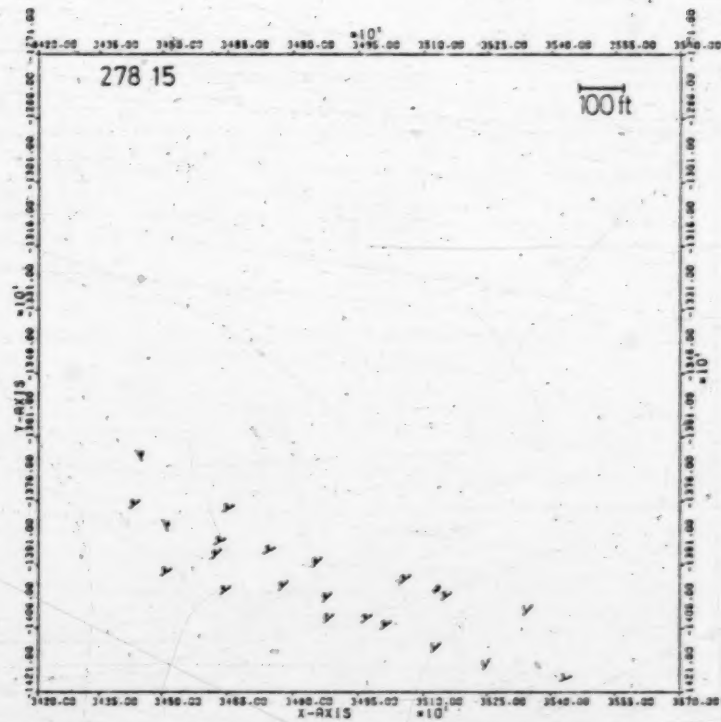
Down plunge profiles with structural interpretation for each of the 45 domains.

LEGEND

Kw.....Wapiabi
Kc.....Cardium
Kb.....Blackstone
Km.....Mountain Park
Kld.....Luscar Member D
Solid black...Jewel Seam
Klb.....Luscar Members B and C
Kla.....Luscar Member A
oooo.....Cadomin
J.....Nikanassin and Fernie Group
P.....Pre-Jurassic

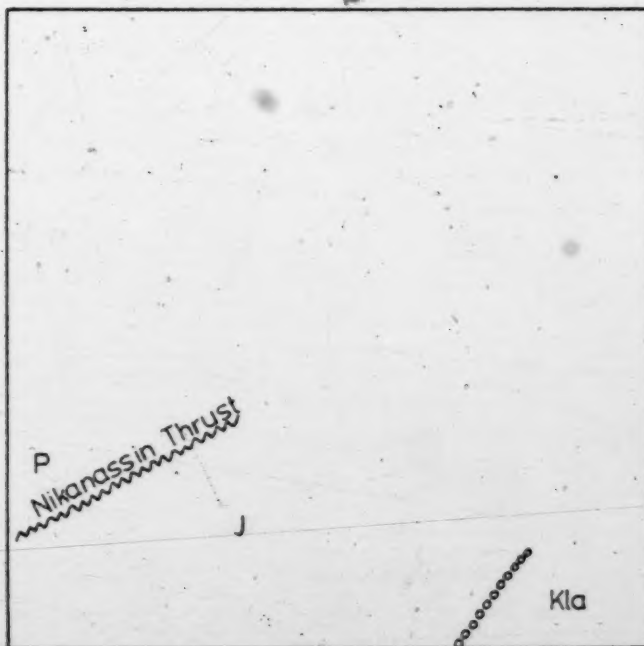
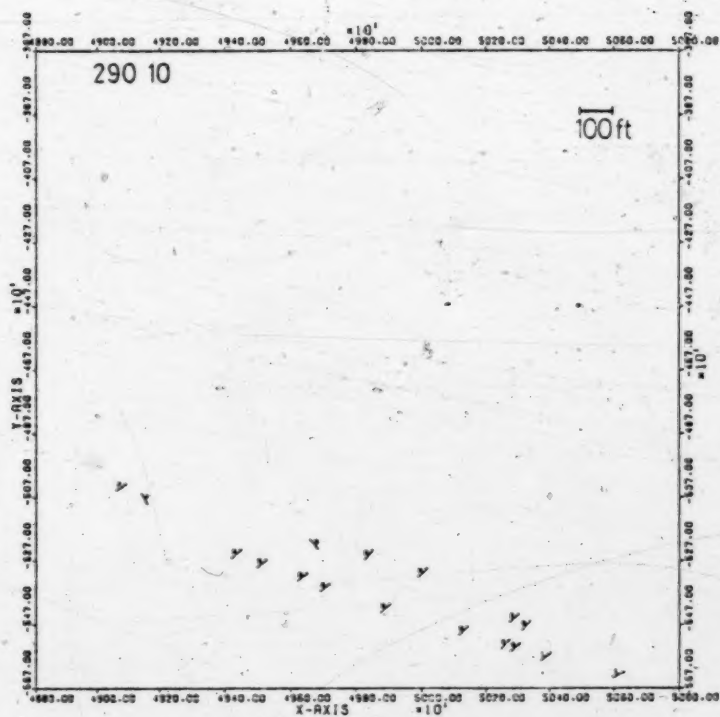
APPENDIX 5-1

DOMAIN I



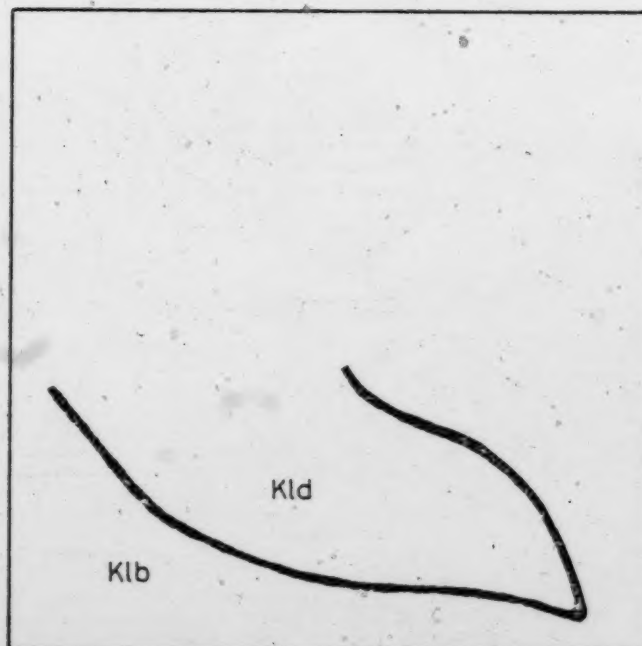
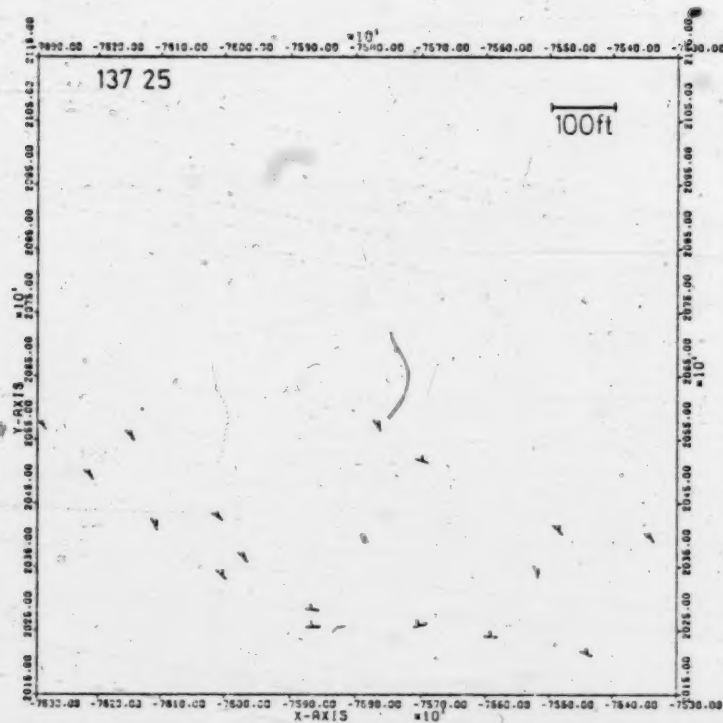
APPENDIX 5-2

DOMAIN 2



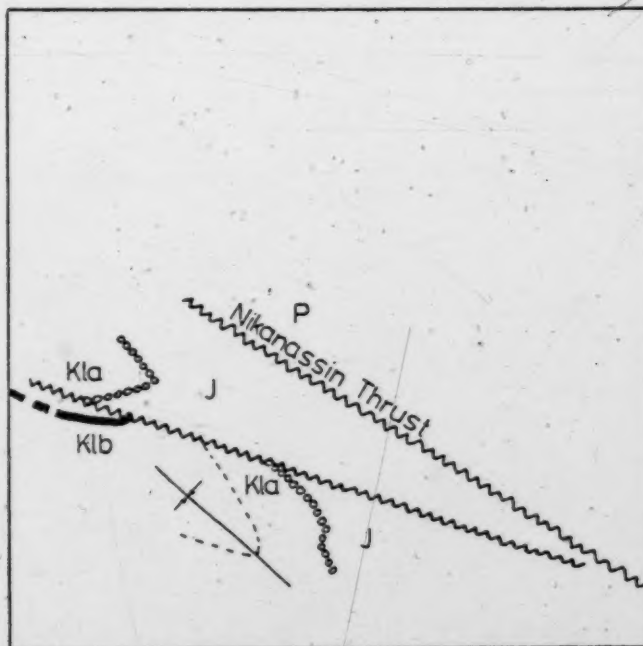
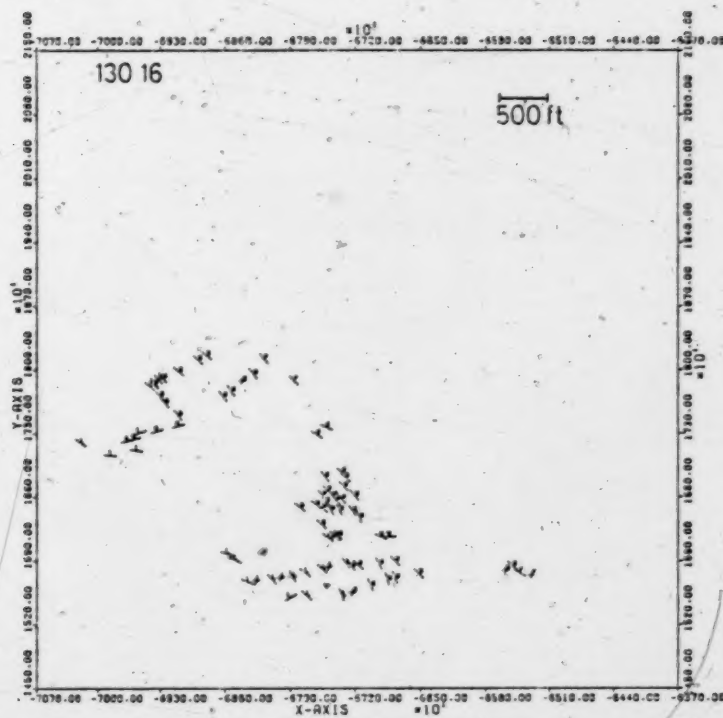
APPENDIX 5-3

DOMAIN 3



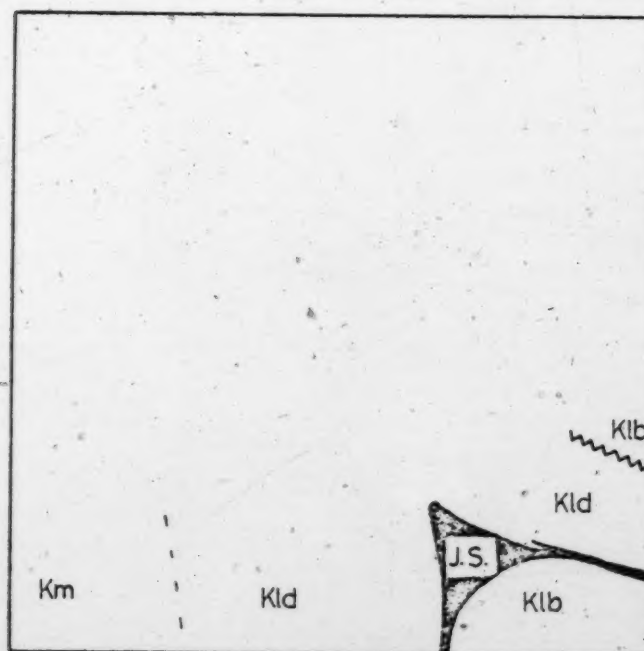
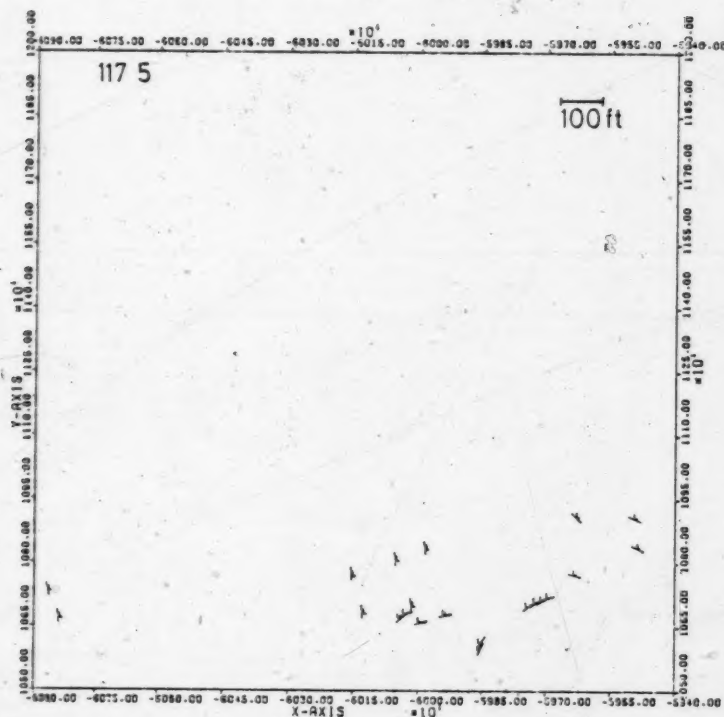
APPENDIX 5-4

DOMAIN 4



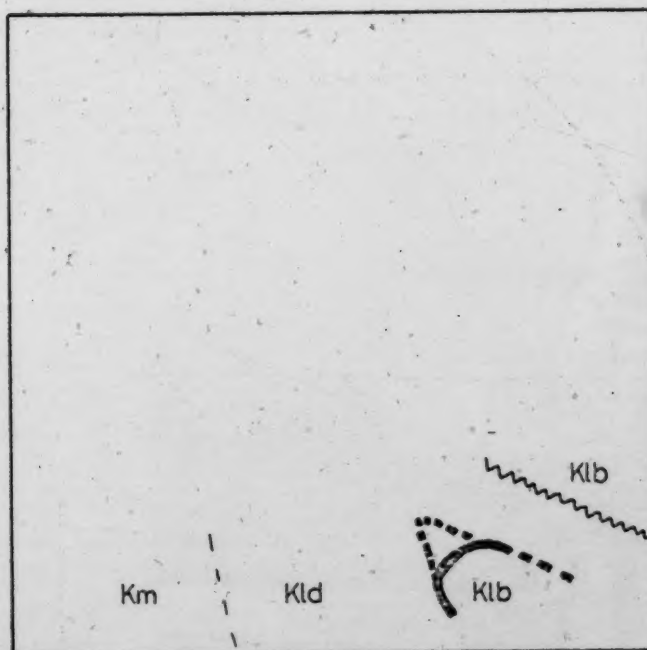
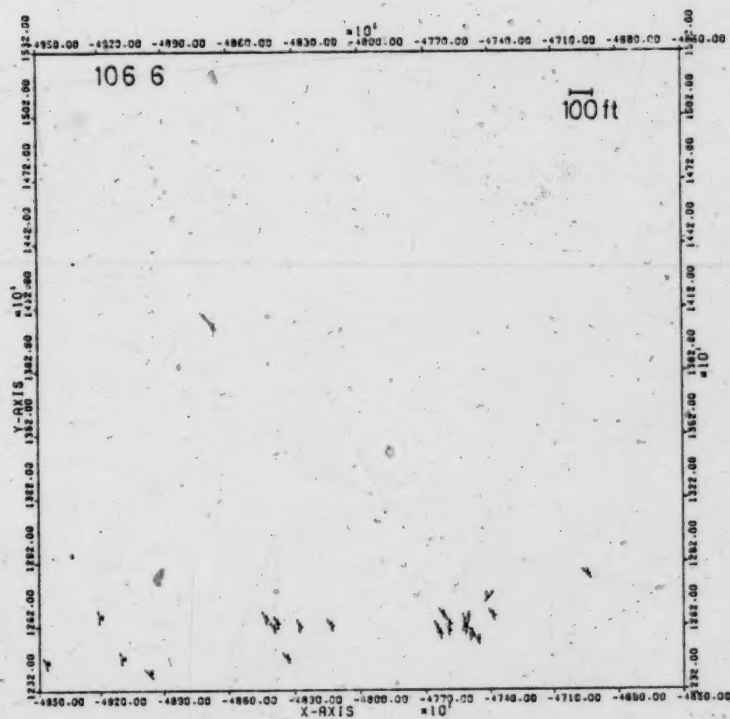
APPENDIX 5-5

DOMAIN 5



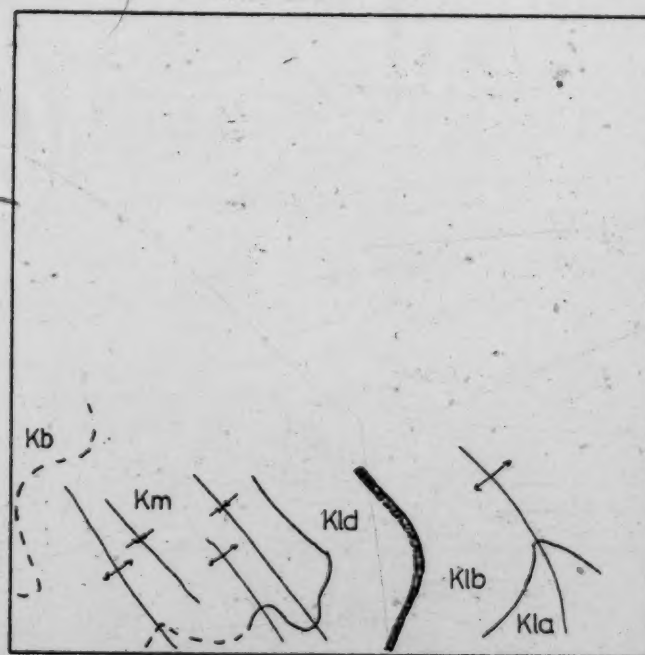
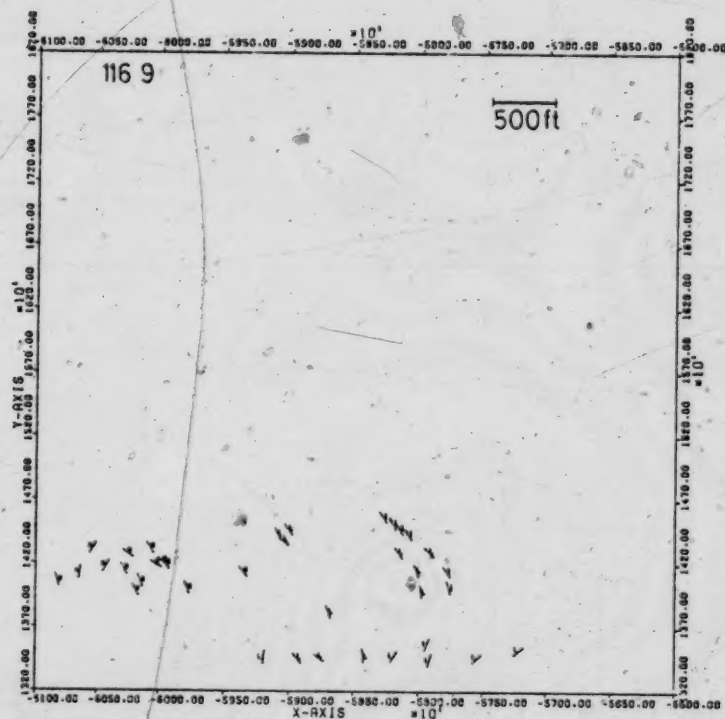
APPENDIX 5 - 6

DOMAIN 6



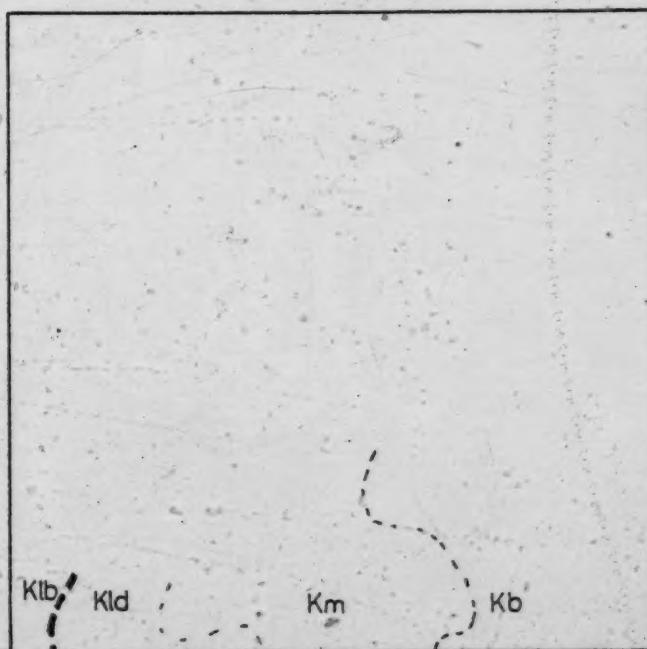
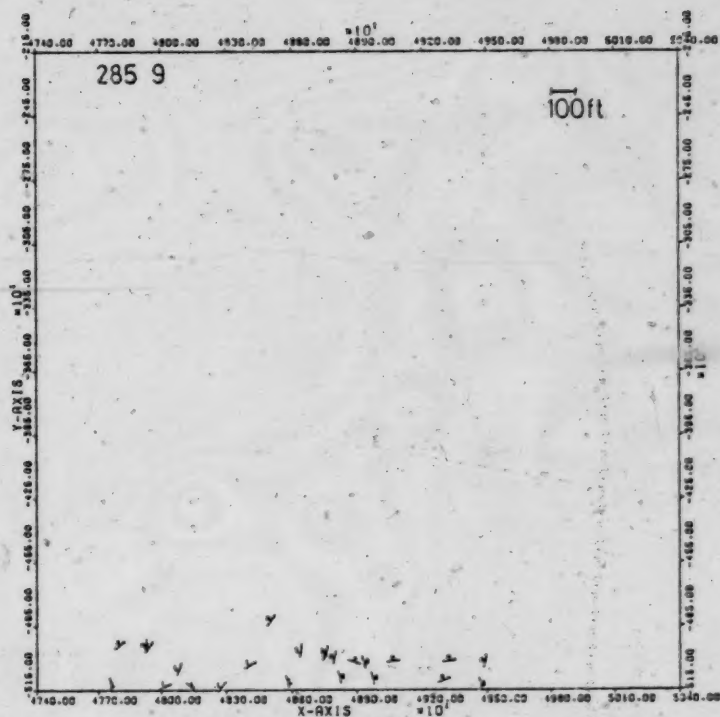
APPENDIX 5-7

DOMAIN 7



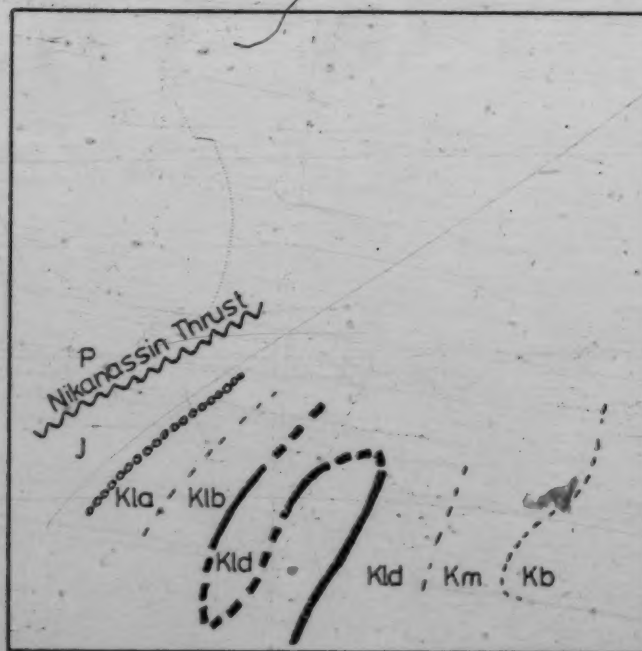
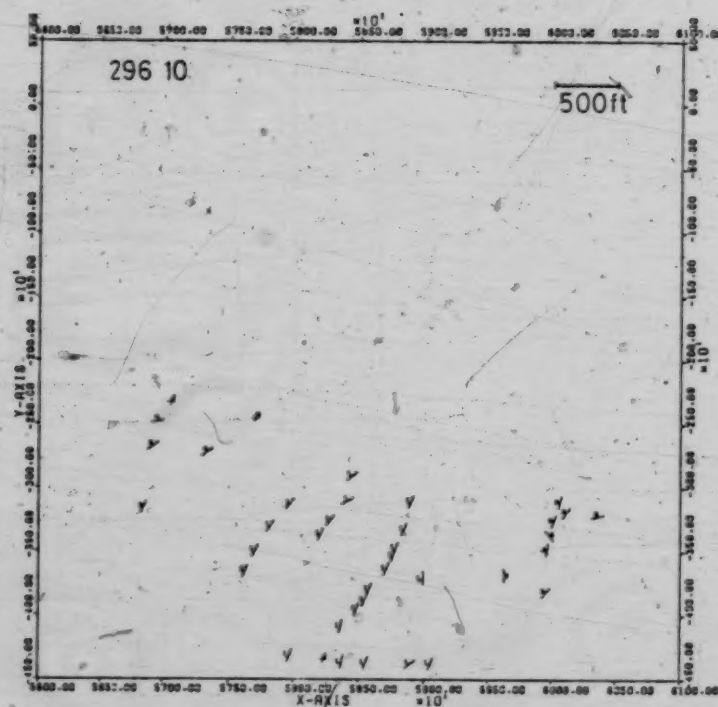
APPENDIX 5-8

DOMAIN 8



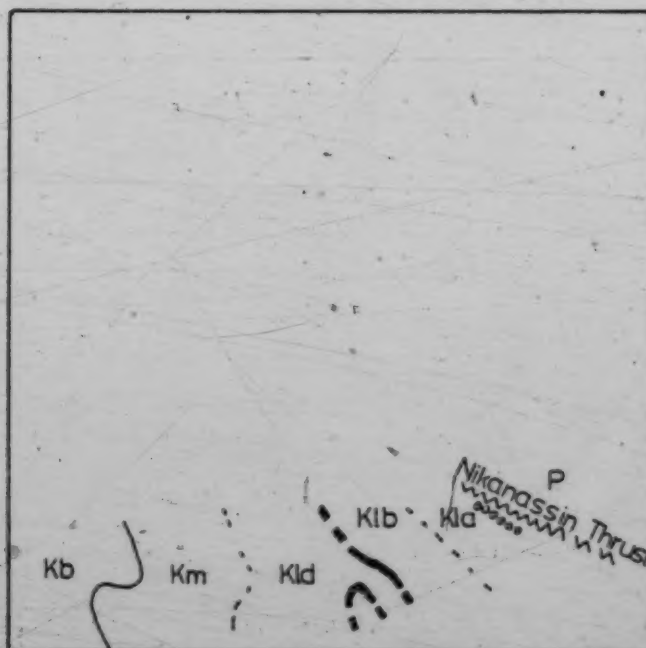
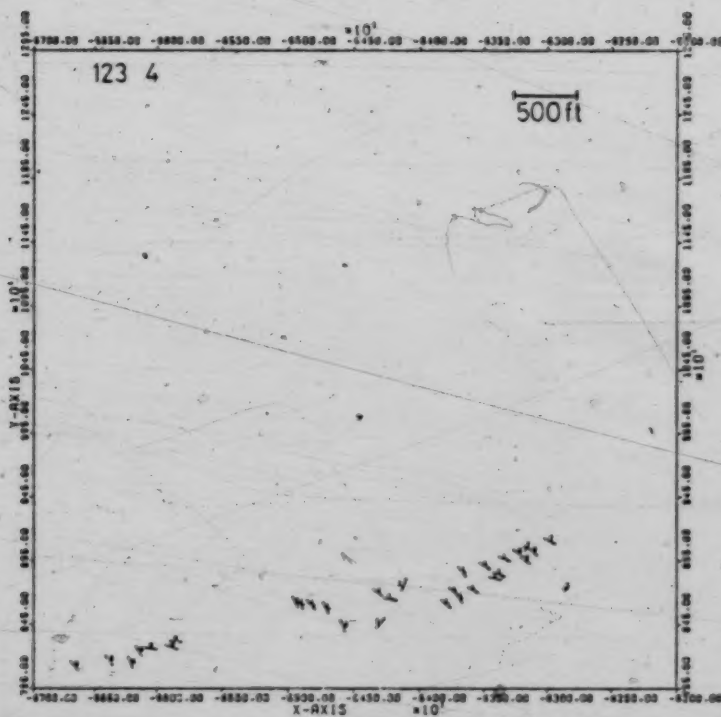
APPENDIX 5-9

DOMAIN 9



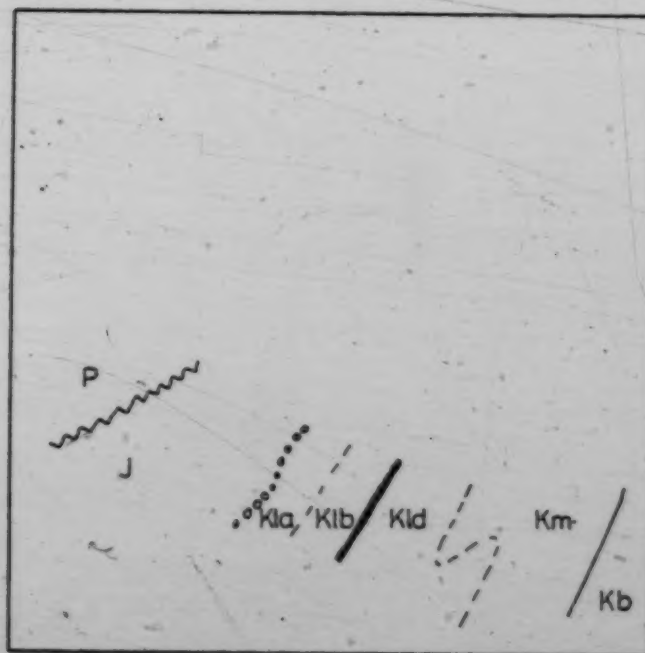
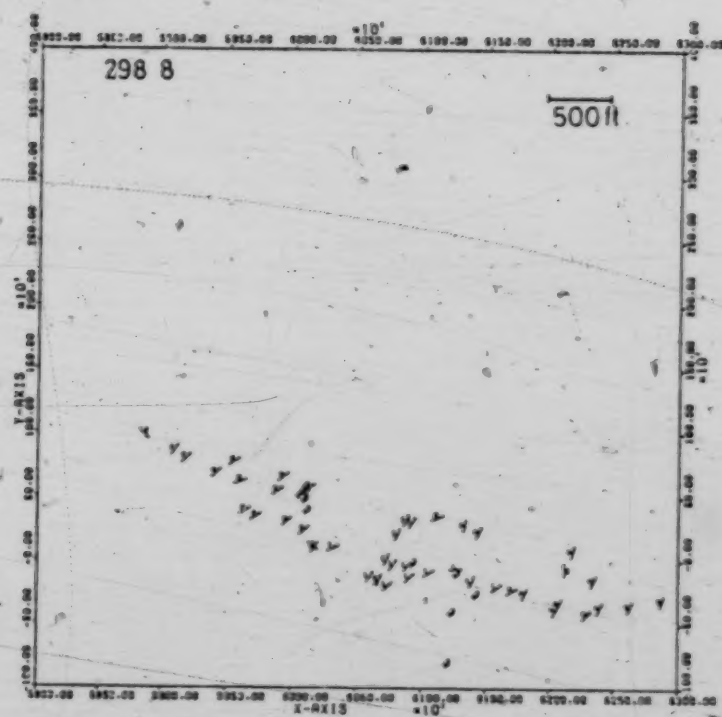
APPENDIX 5-10

DOMAIN 10



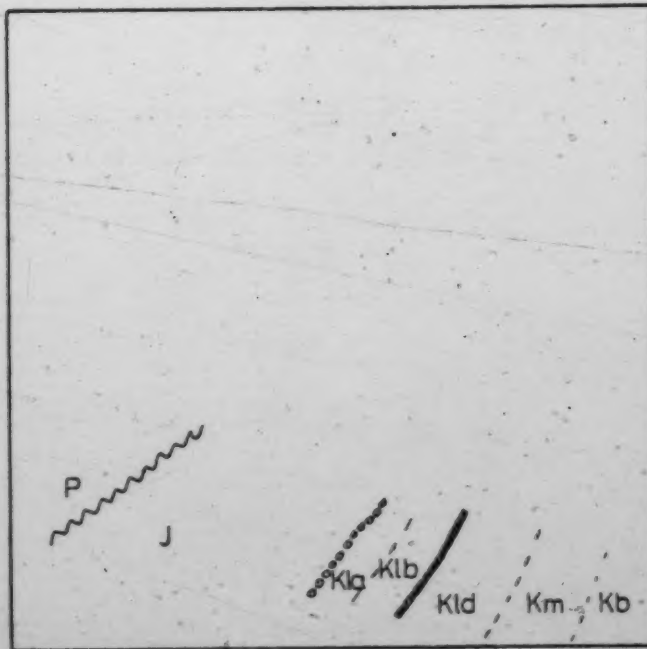
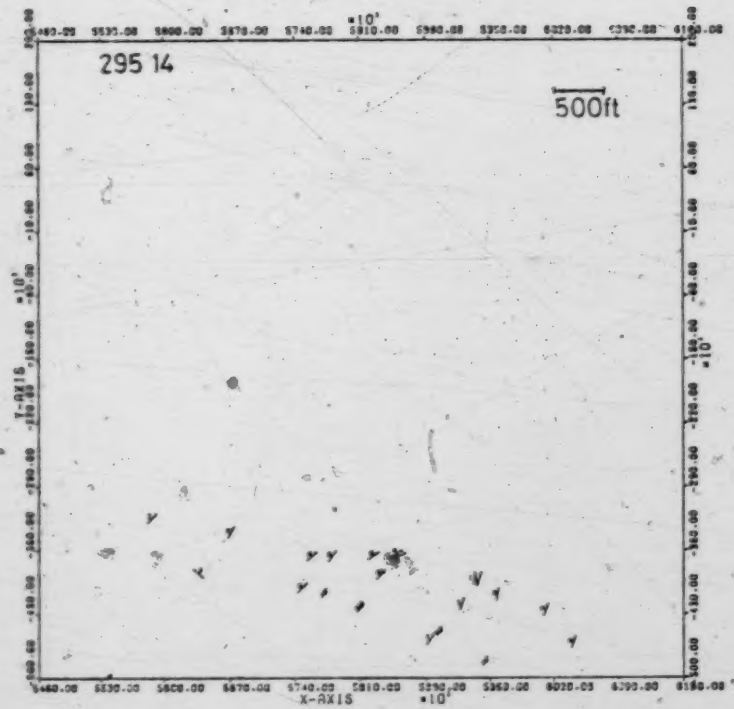
APPENDIX 5-11

DOMAIN 11



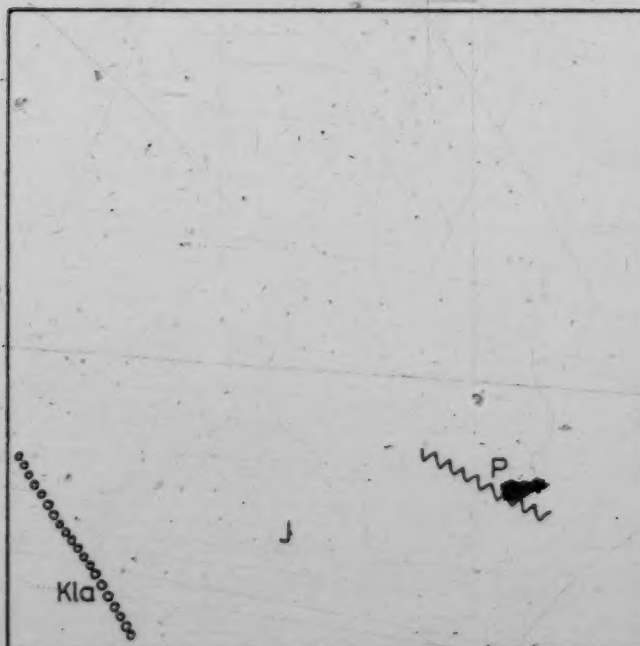
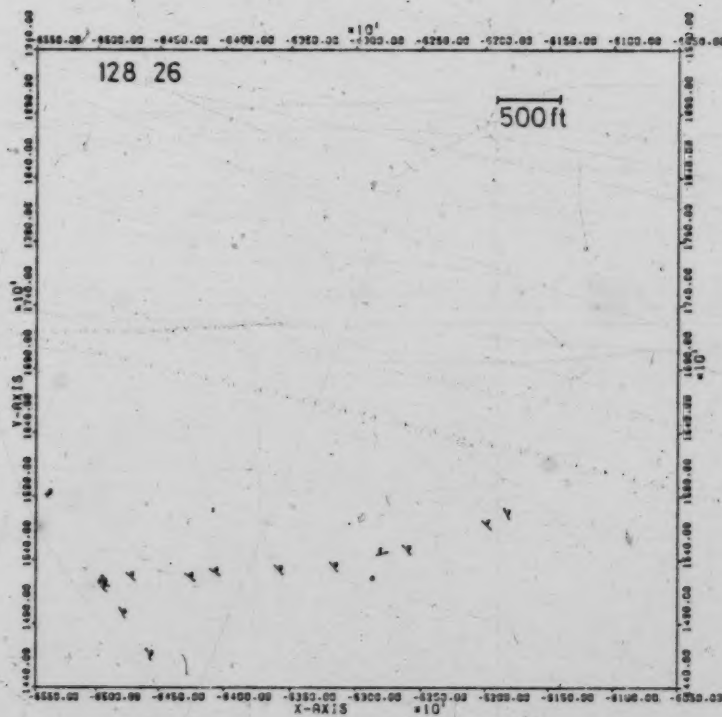
APPENDIX 5-12

DOMAIN 12



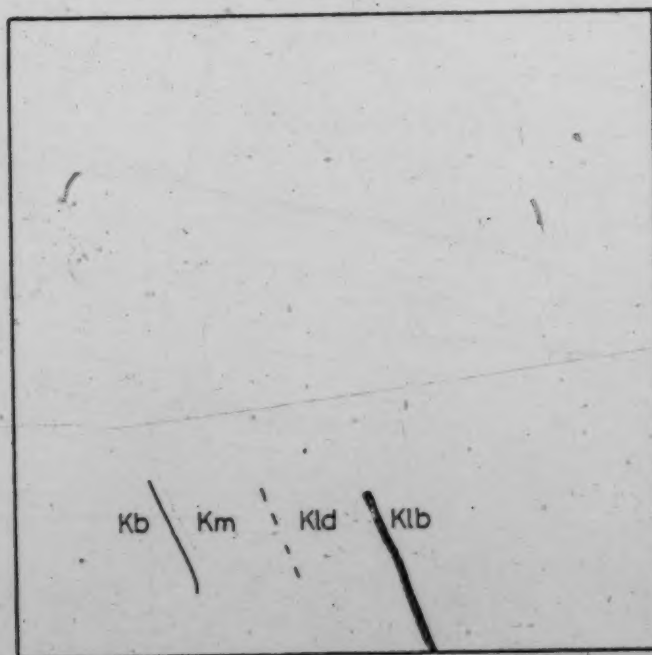
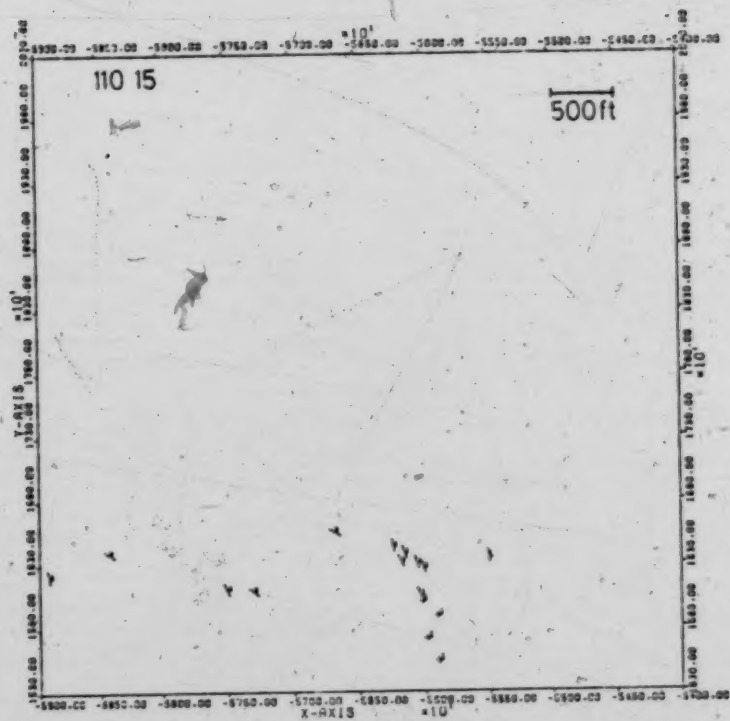
APPENDIX 5-13

DOMAIN 13



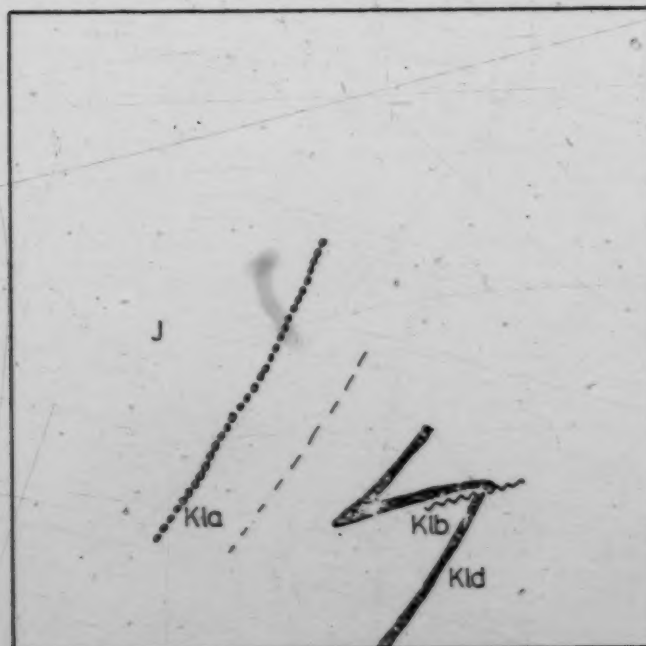
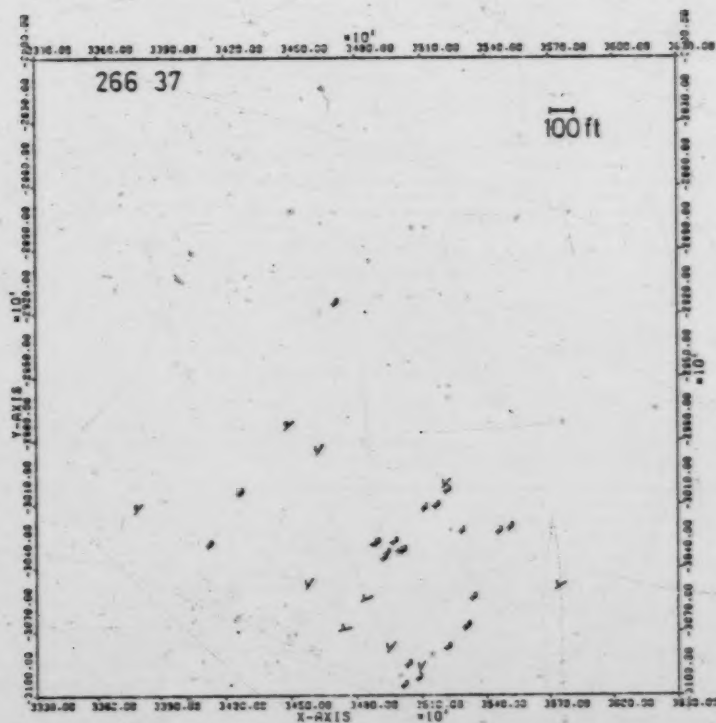
APPENDIX 5-14

DOMAIN 14



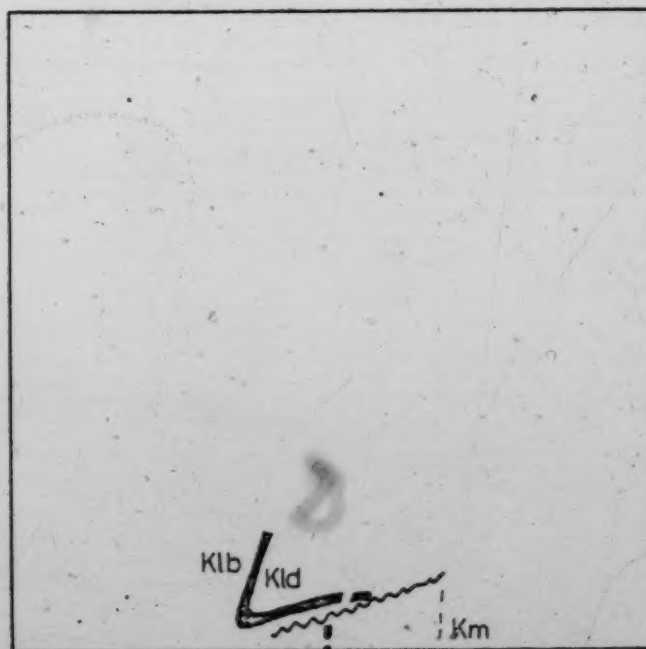
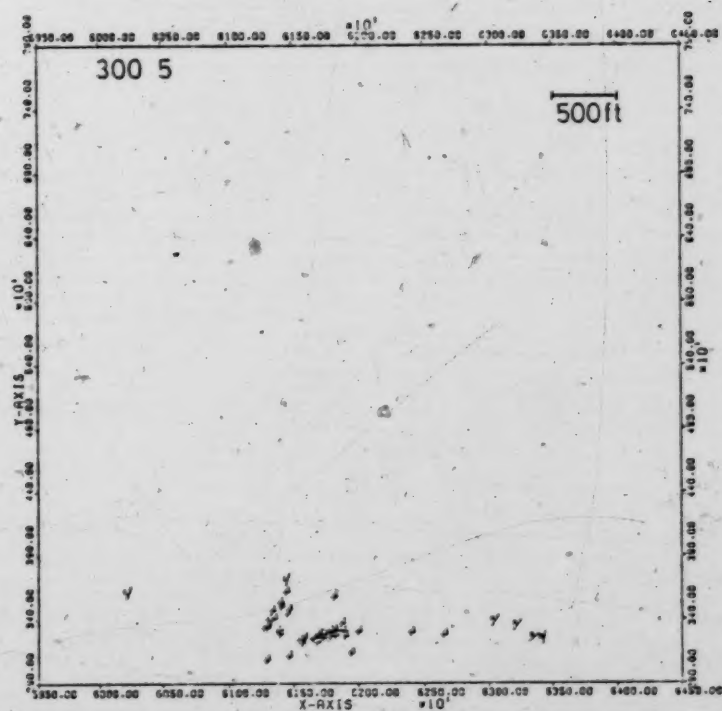
APPENDIX 5-15

DOMAIN 15



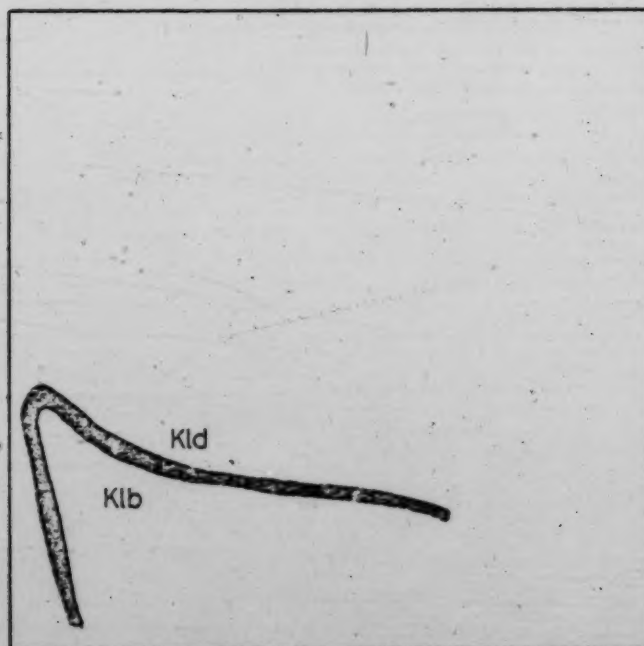
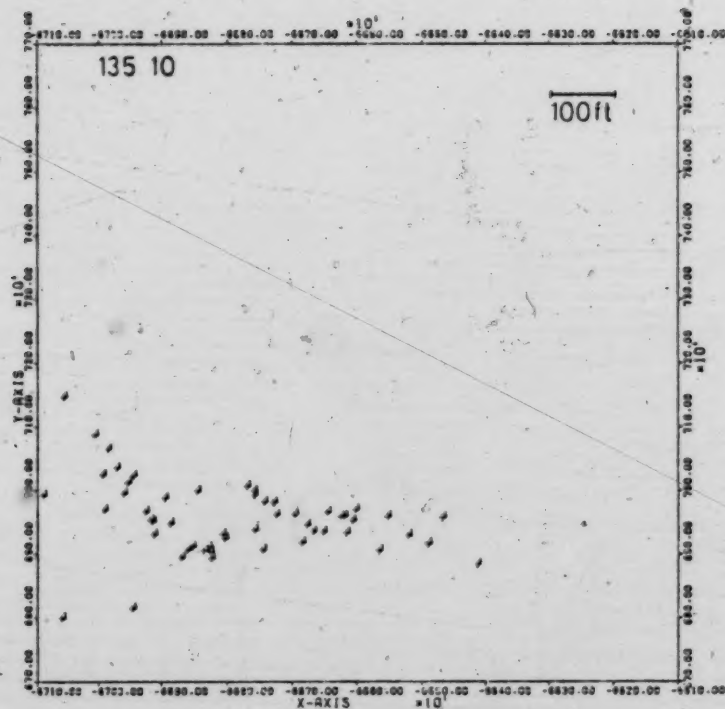
APPENDIX 5-16

DOMAIN 16



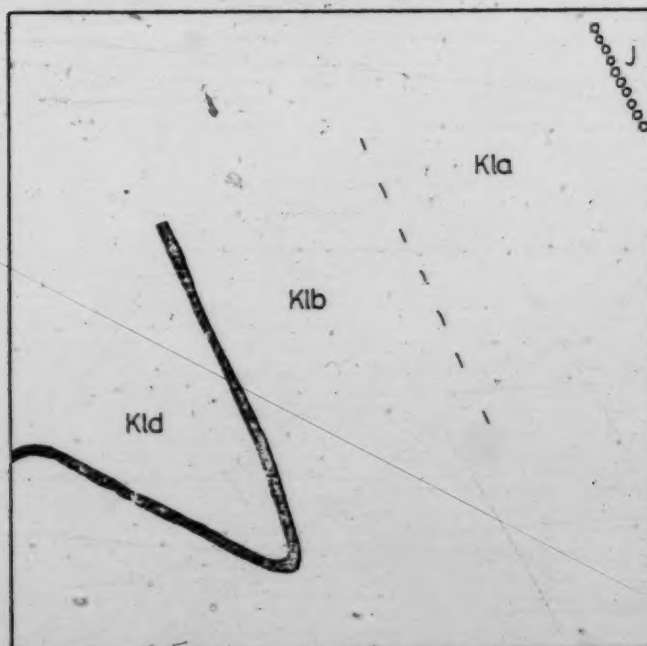
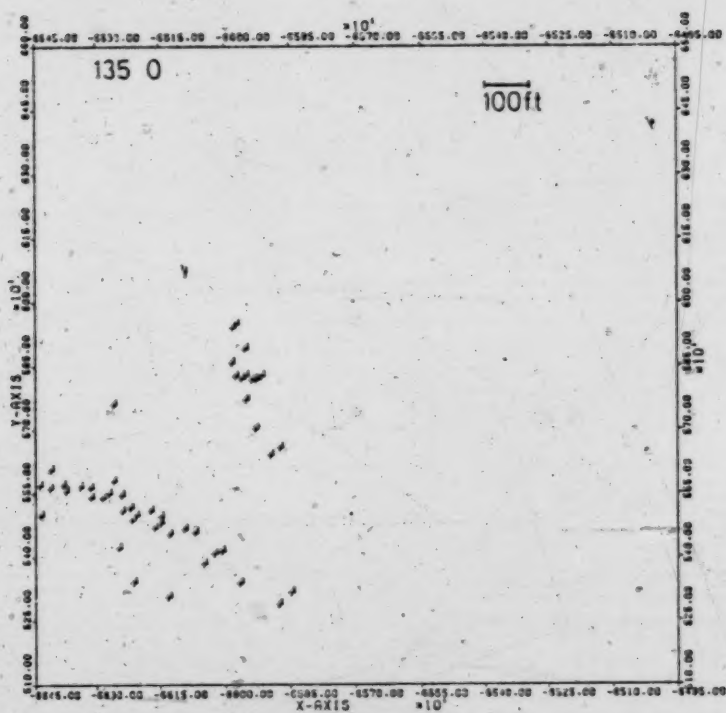
APPENDIX 5-17

DOMAIN 17



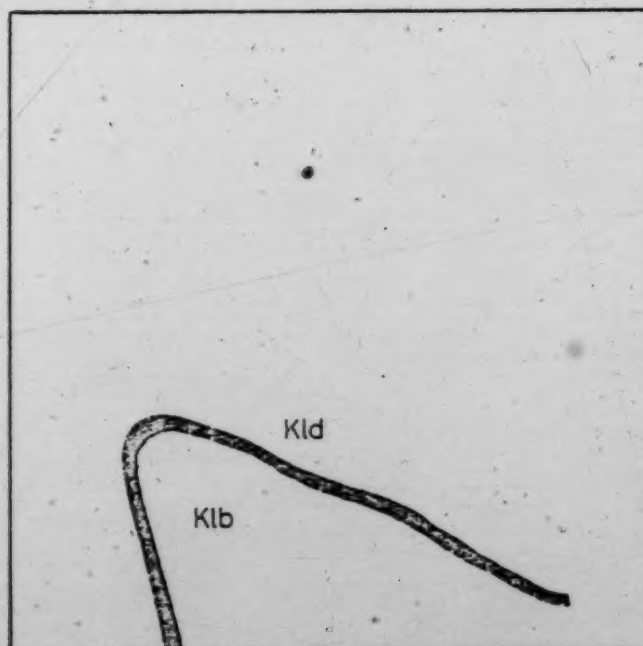
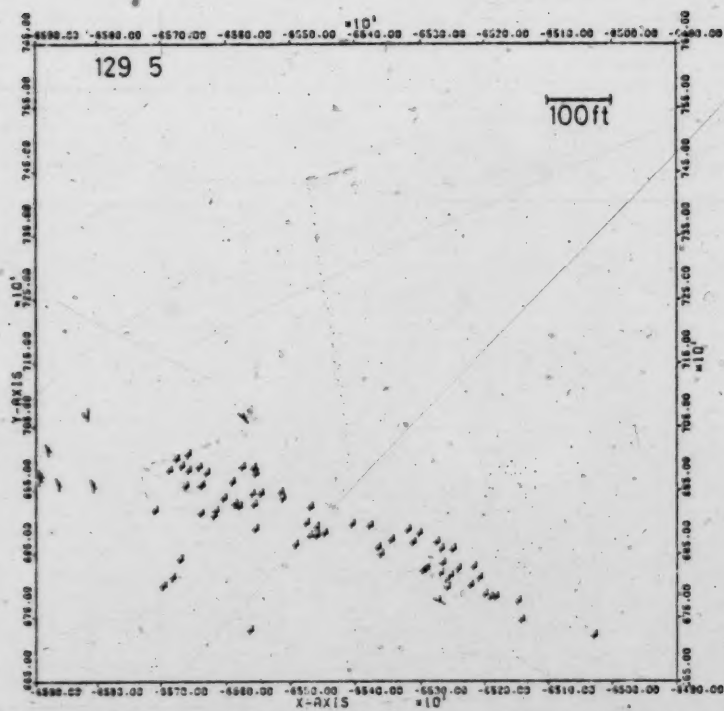
APPENDIX 5-18

DOMAIN 18



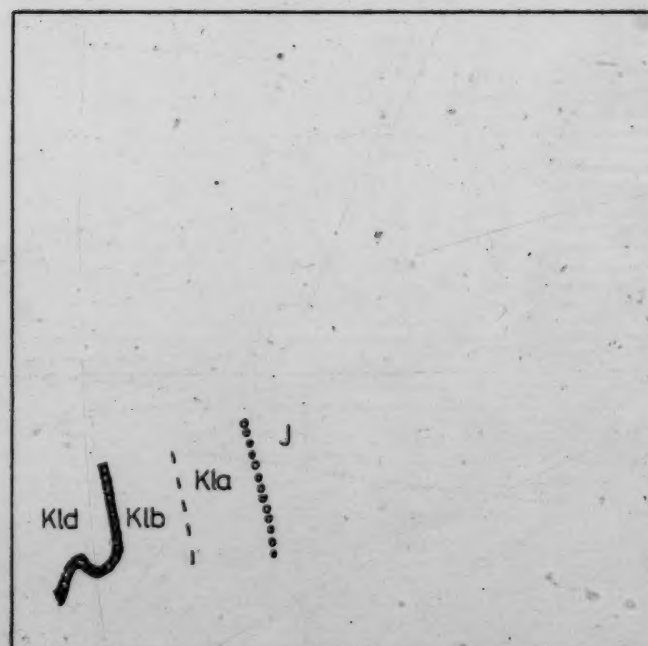
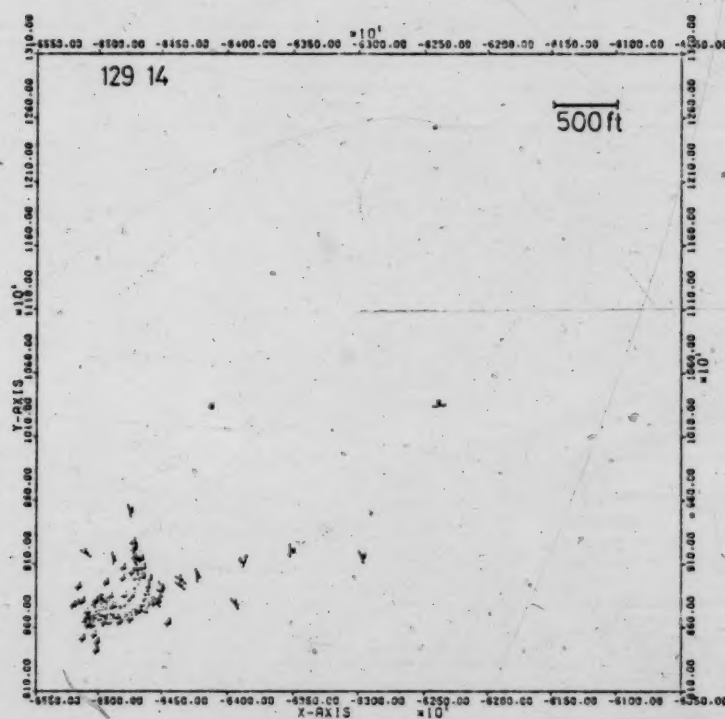
APPENDIX 5-19

DOMAIN 19



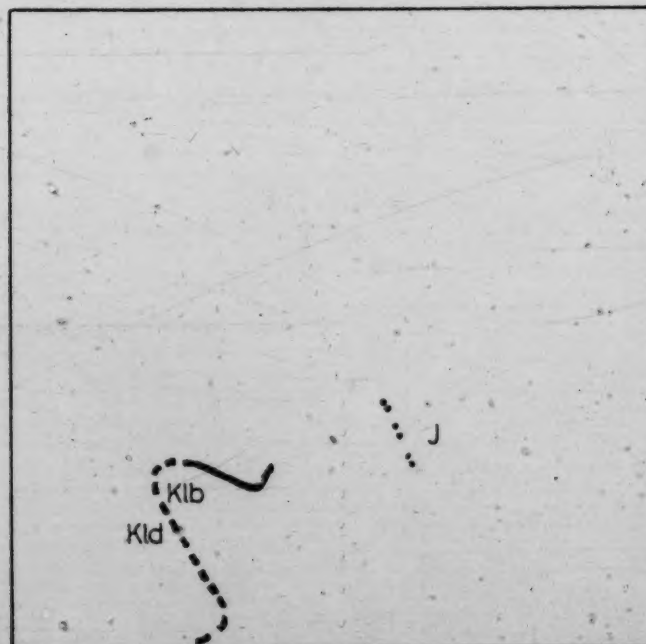
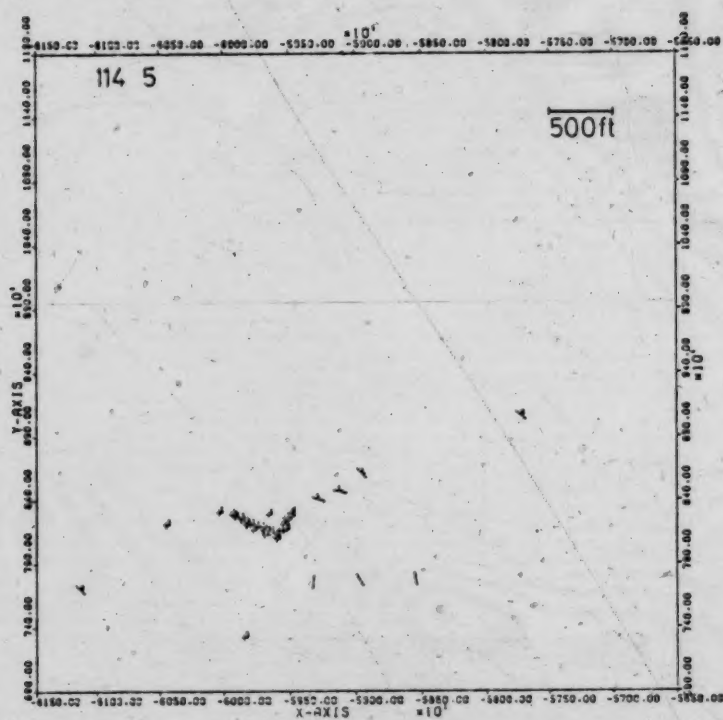
APPENDIX 5-20

DOMAIN 20



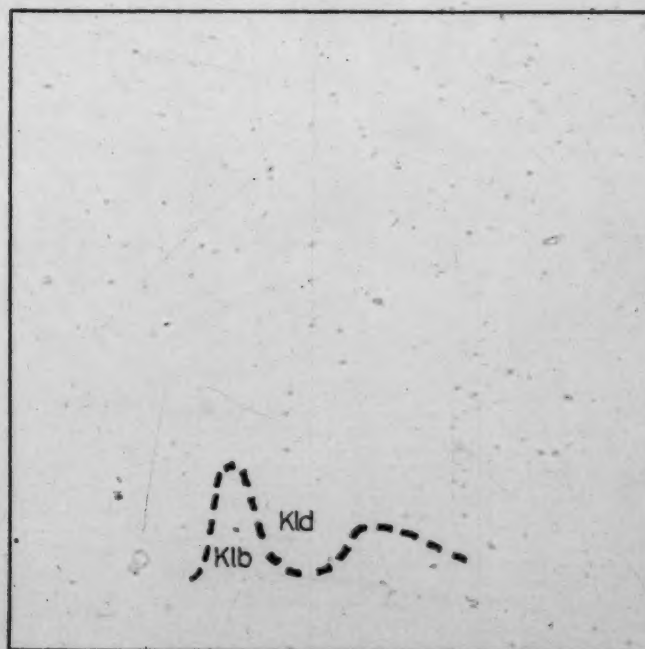
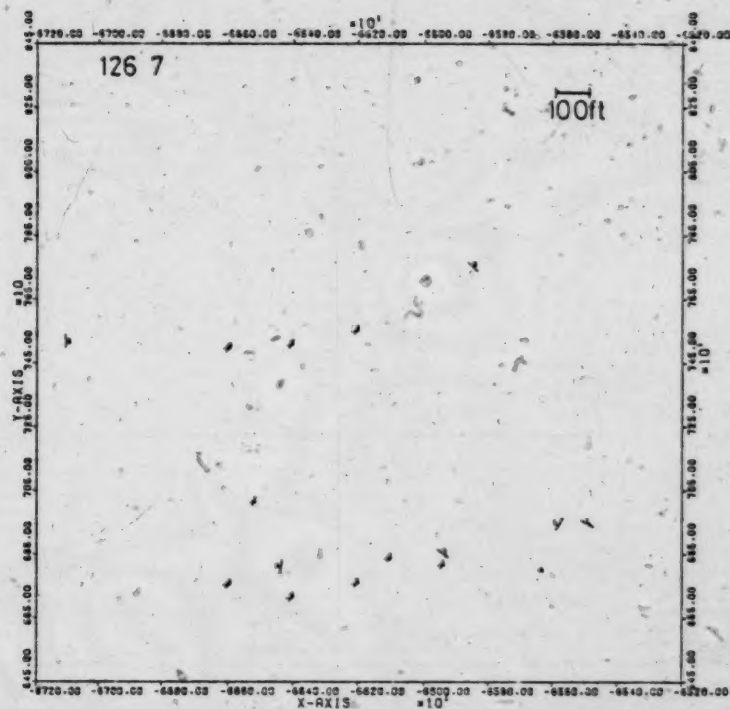
APPENDIX 5-21

DOMAIN 21



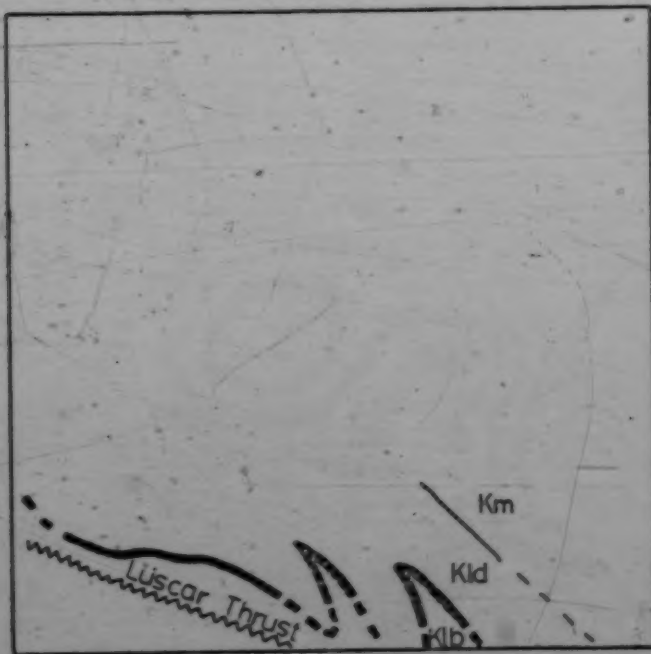
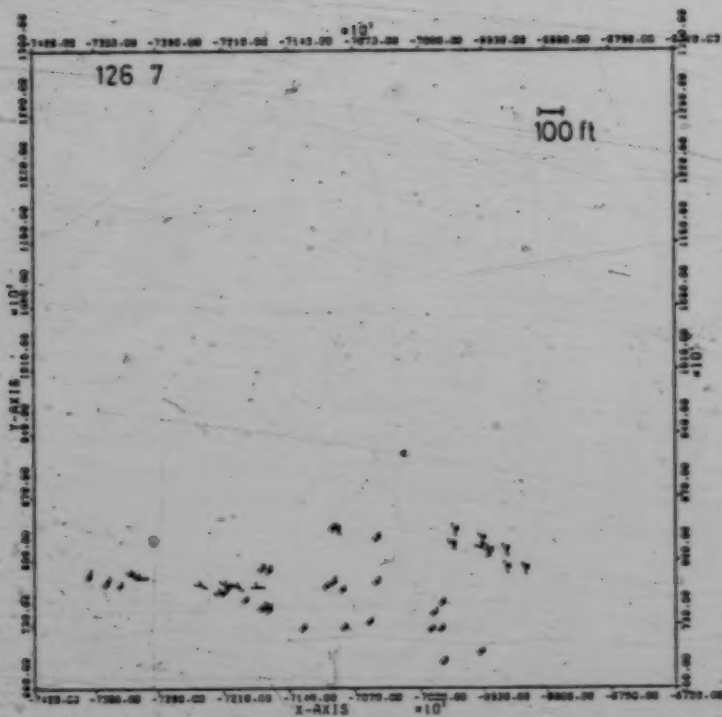
APPENDIX 5-22

DOMAIN 22



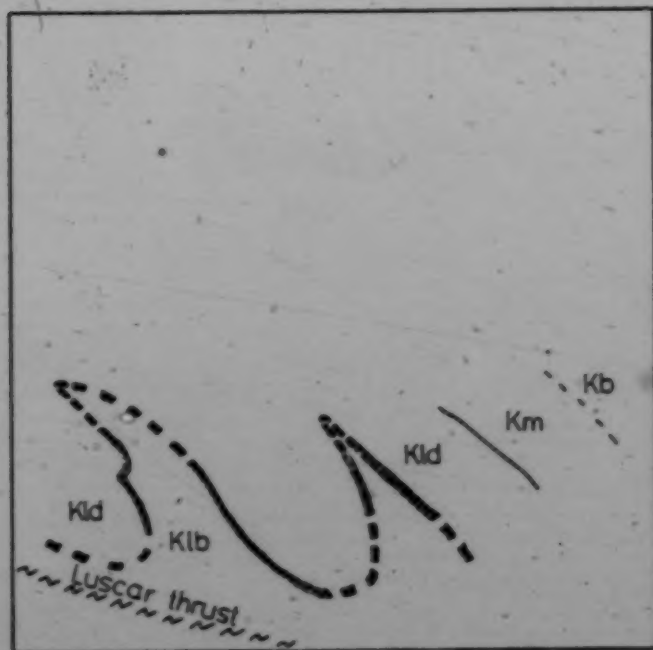
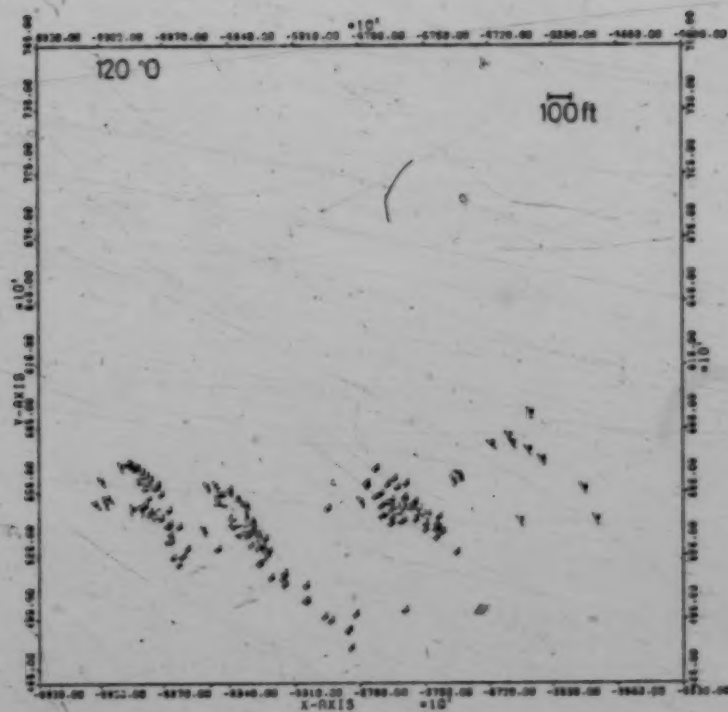
APPENDIX 5-23

DOMAIN 23



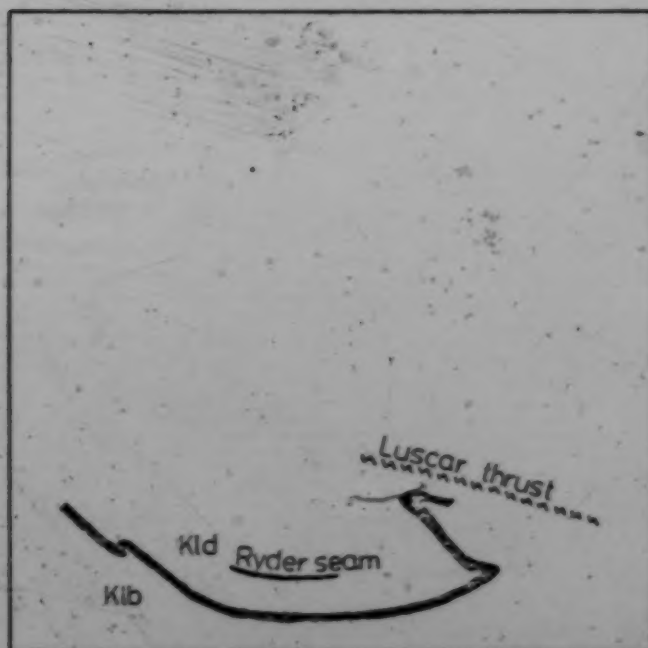
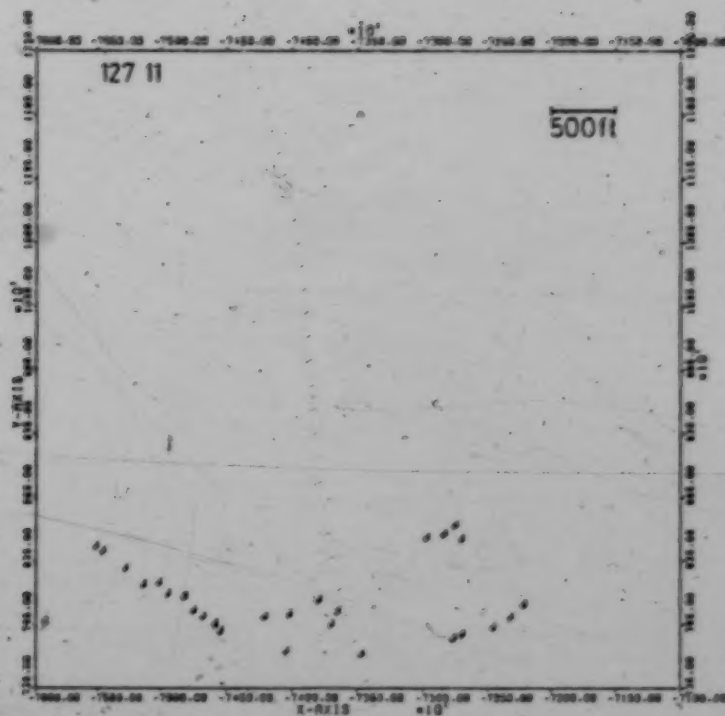
APPENDIX 5-24

DOMAIN 24



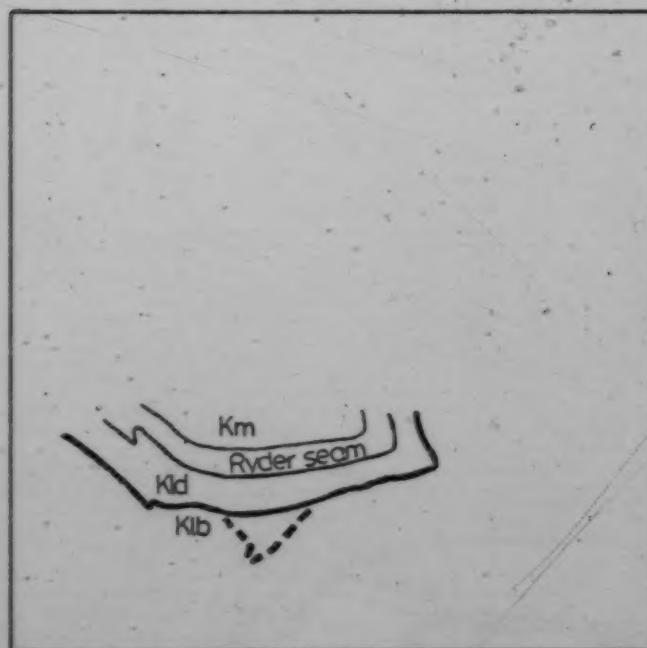
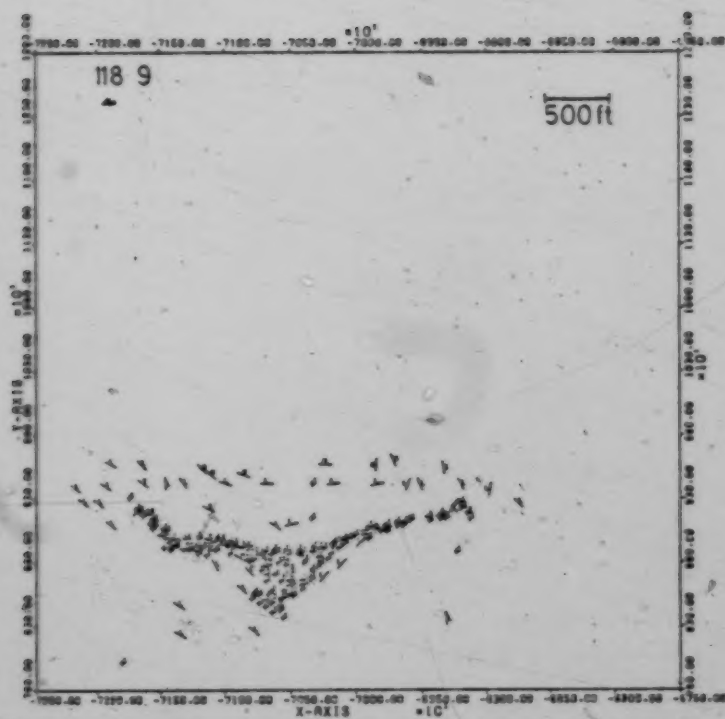
APPENDIX 5-25

DOMAIN 25



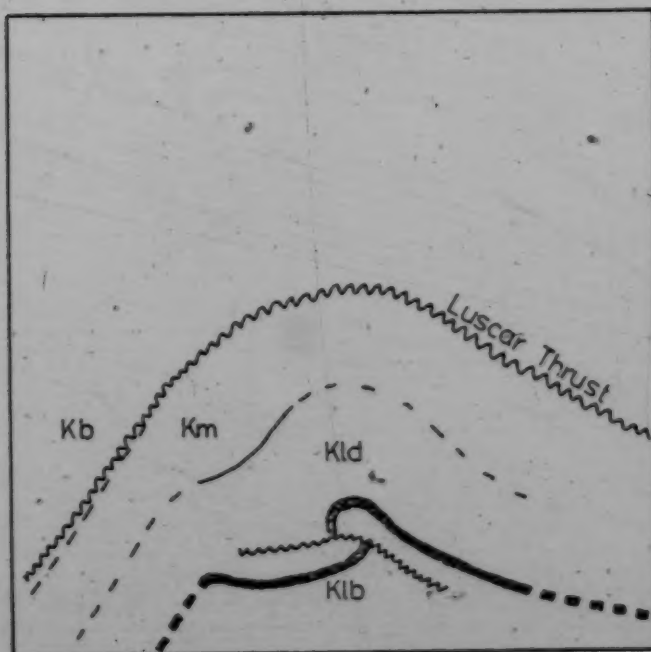
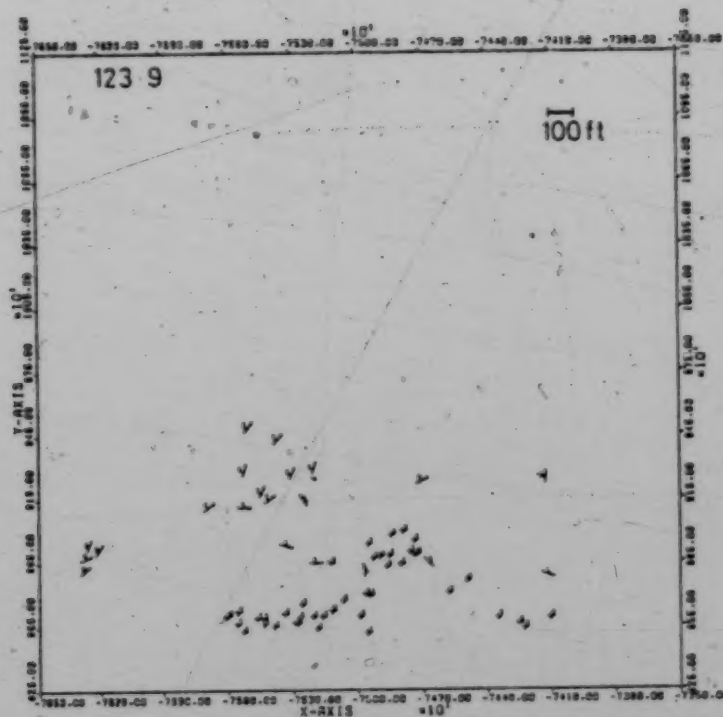
APPENDIX 5-26

DOMAIN 26



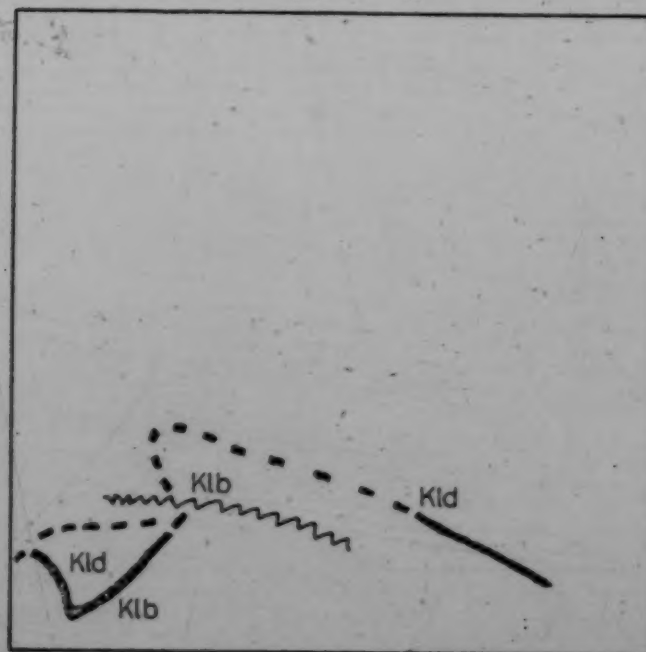
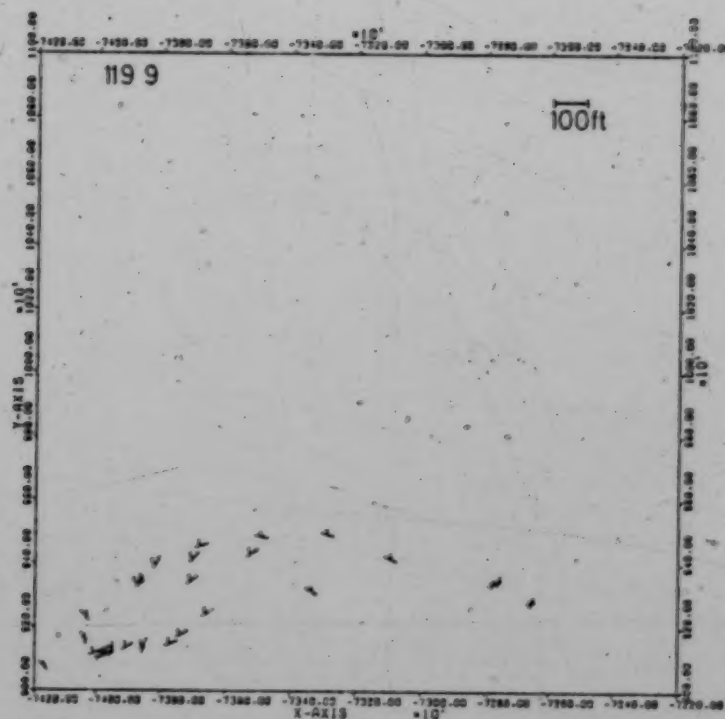
APPENDIX 5-27

DOMAIN 27



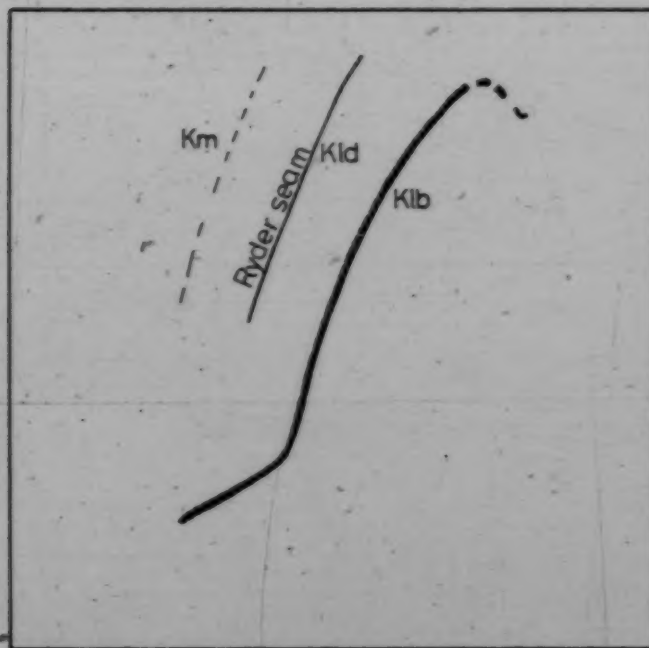
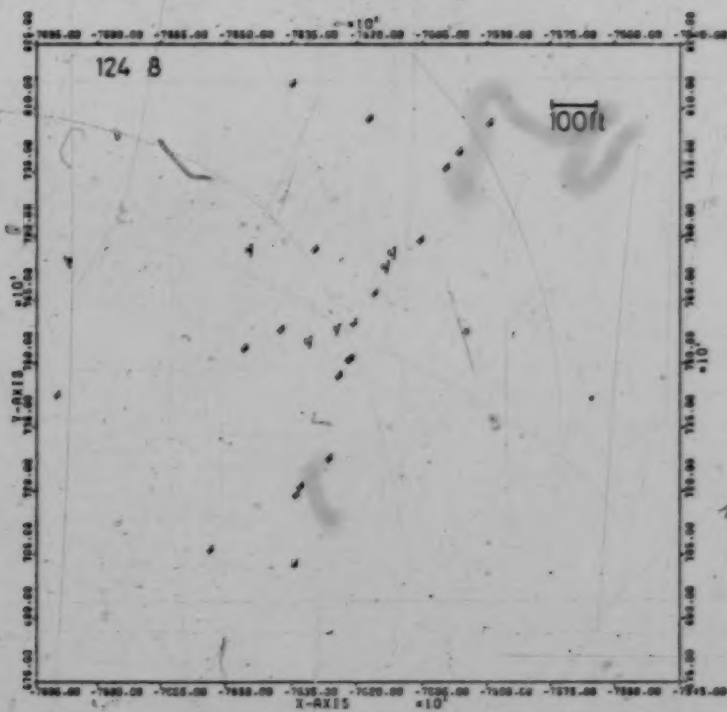
APPENDIX 5-28

DOMAIN 28



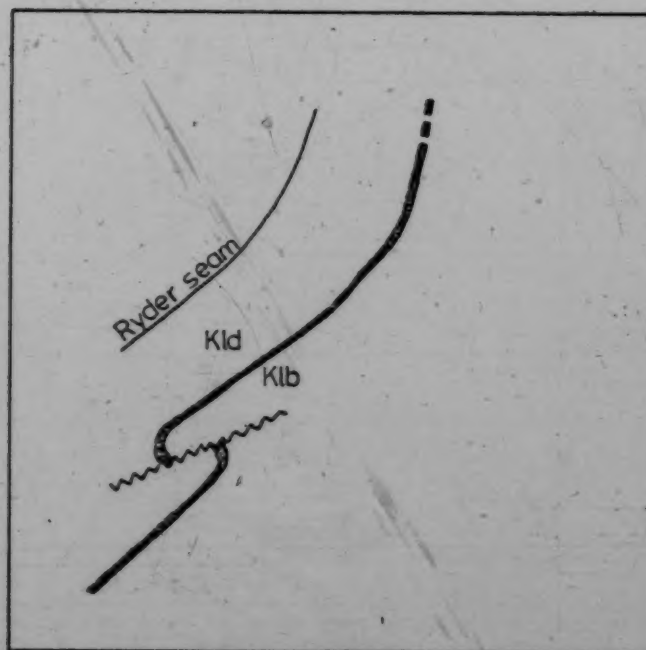
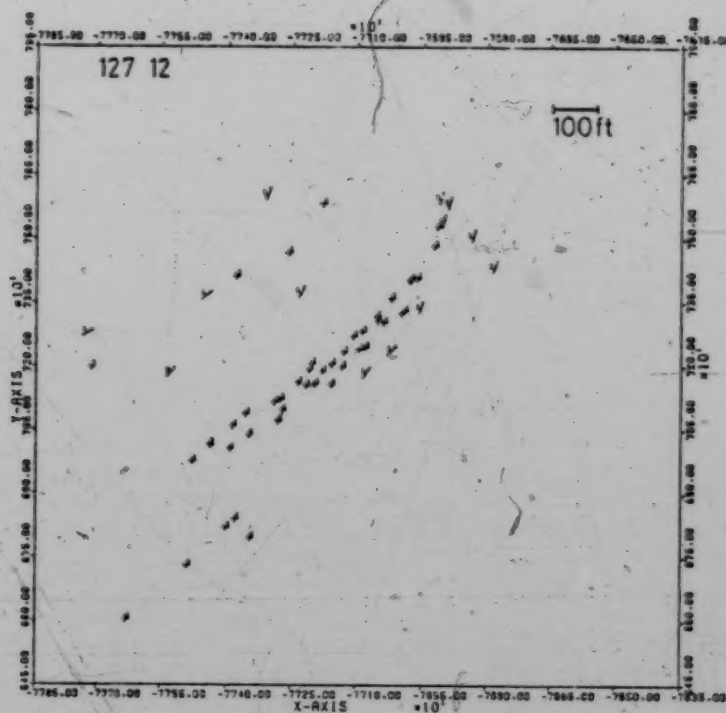
APPENDIX 5-29

DOMAIN 29



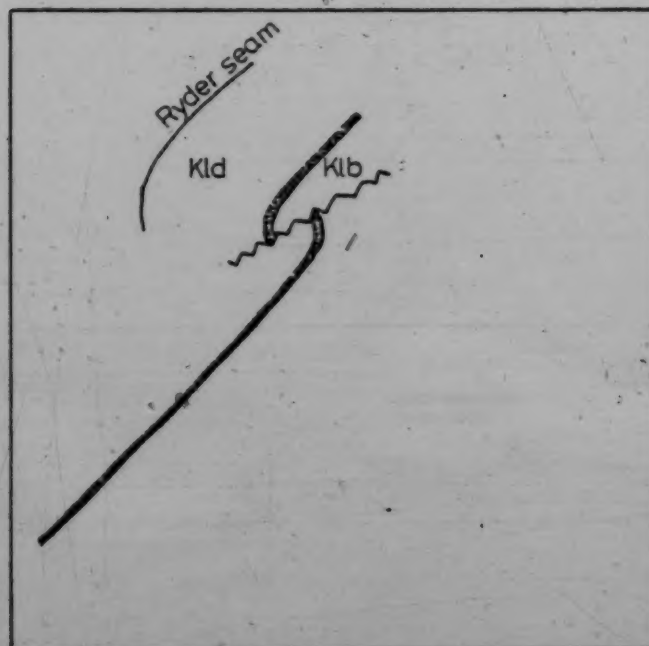
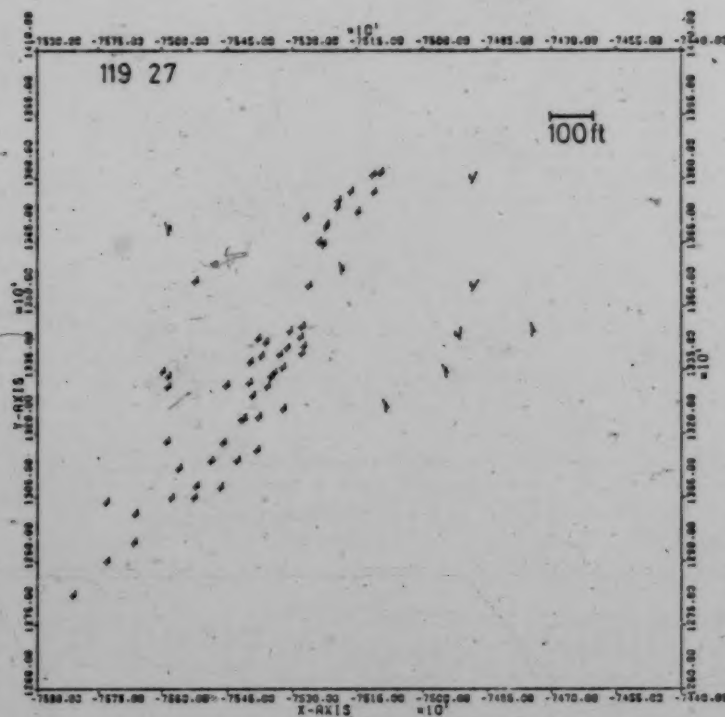
APPENDIX 5-30

DOMAIN 30



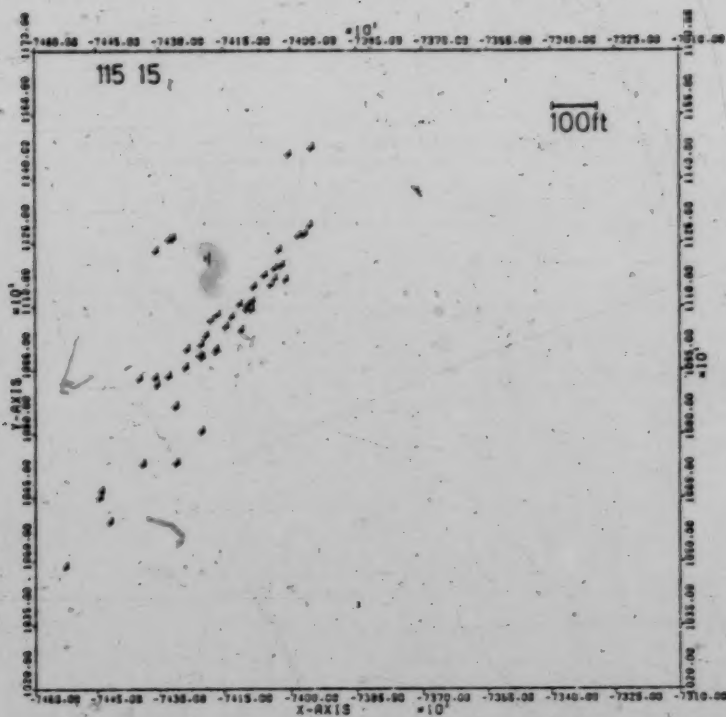
APPENDIX 5-31

DOMAIN 31



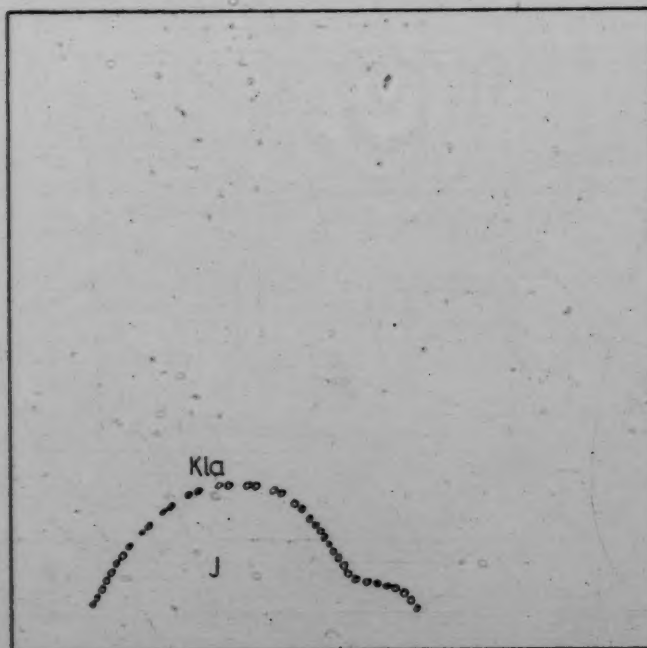
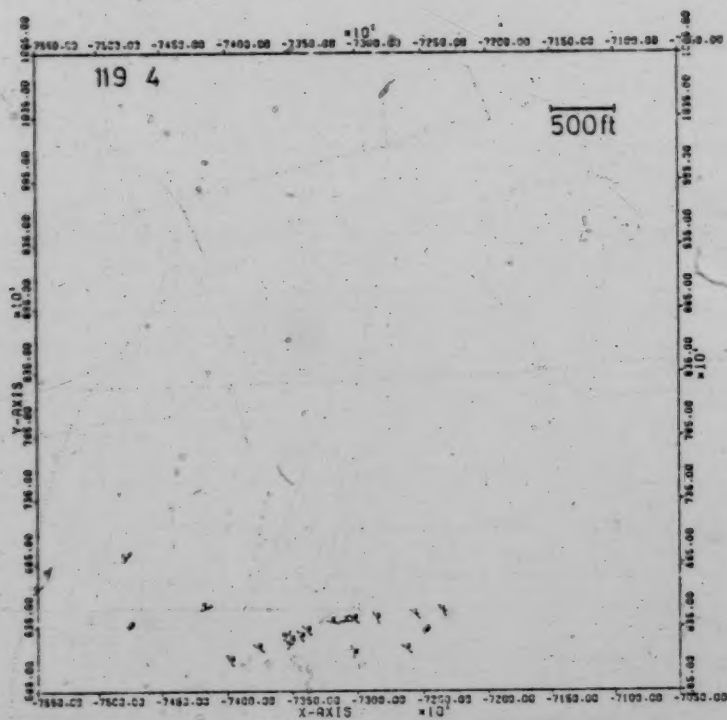
APPENDIX 5-32

DOMAIN 32



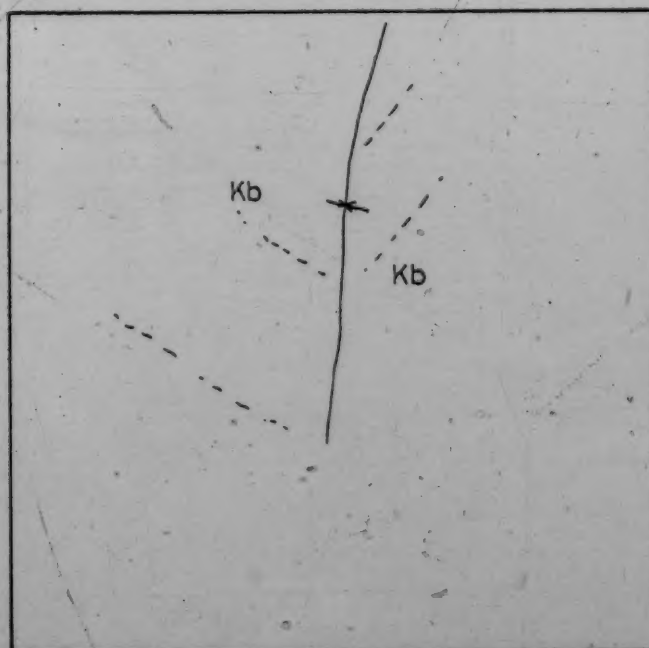
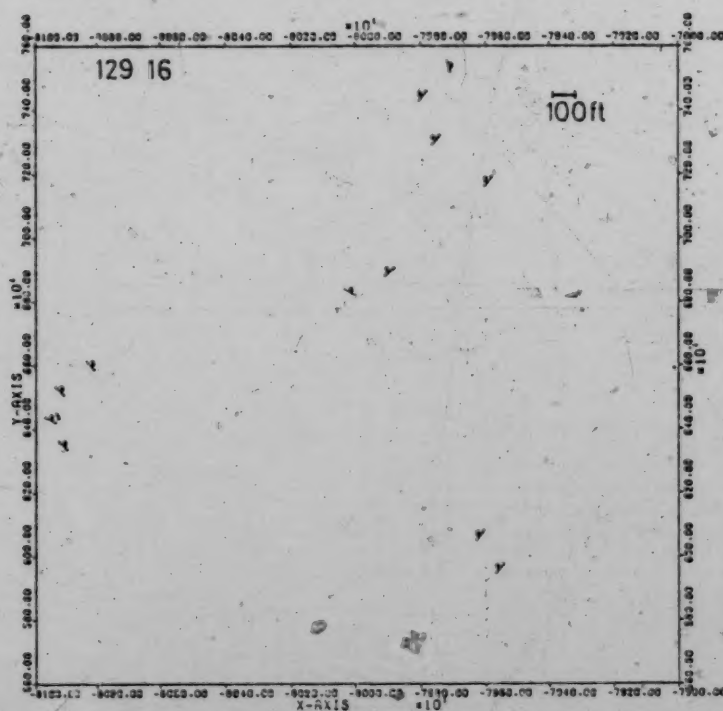
APPENDIX 5-33

DOMAIN 33



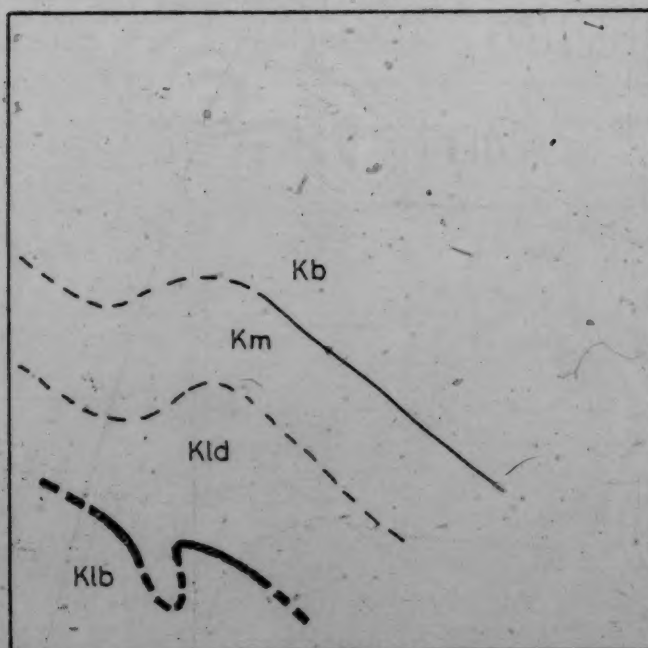
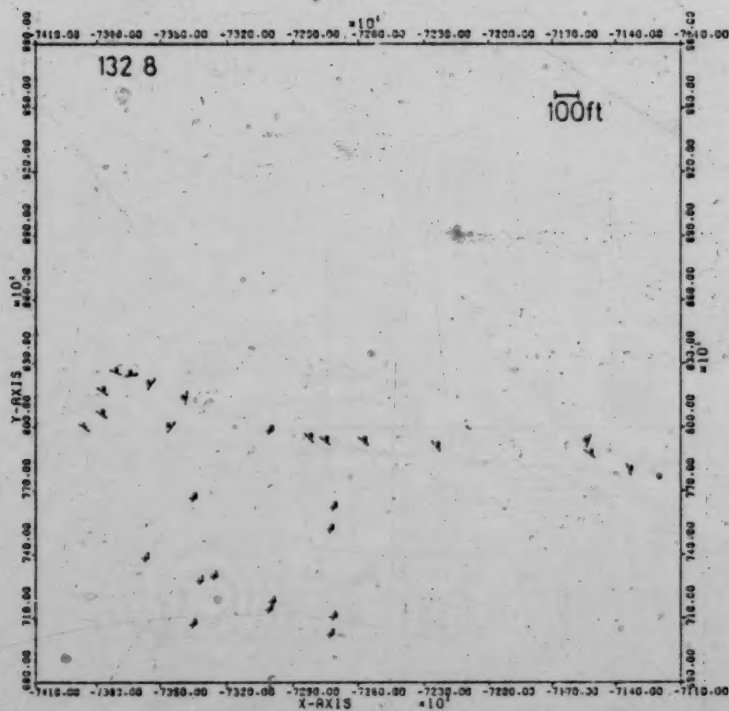
APPENDIX 5-34

DOMAIN 34



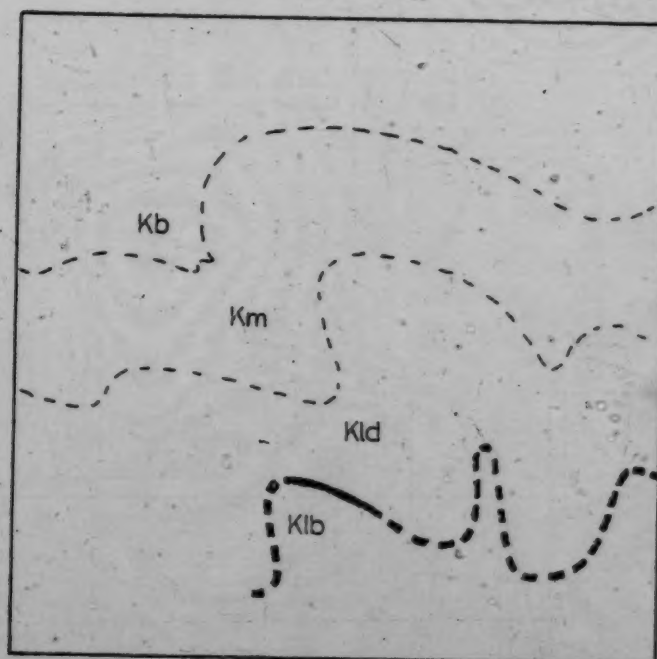
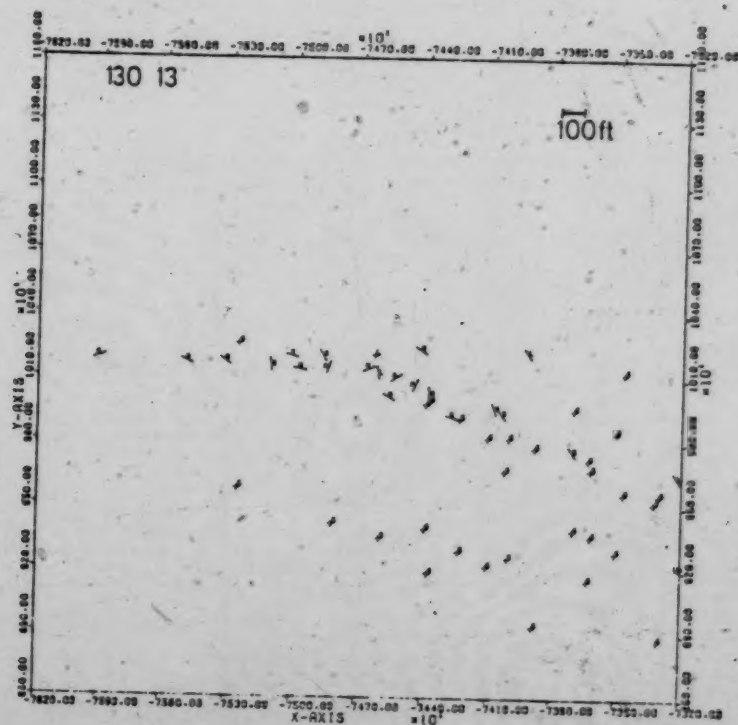
APPENDIX 5-35

DOMAIN 35



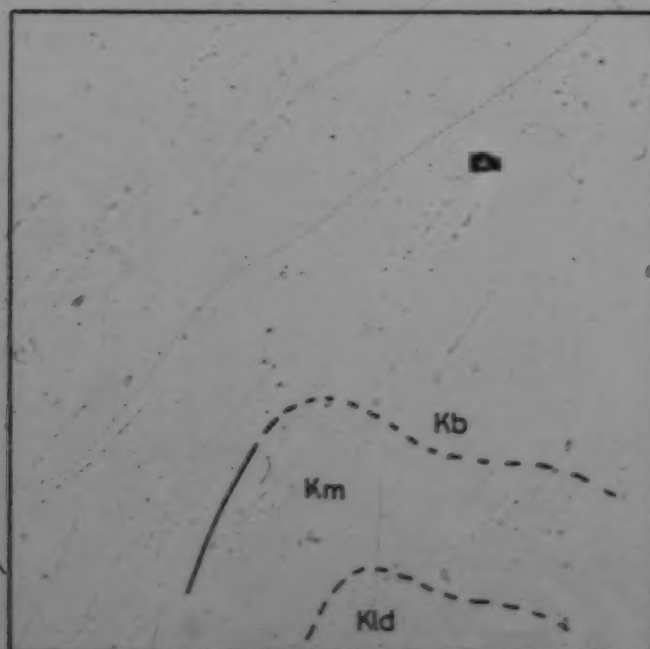
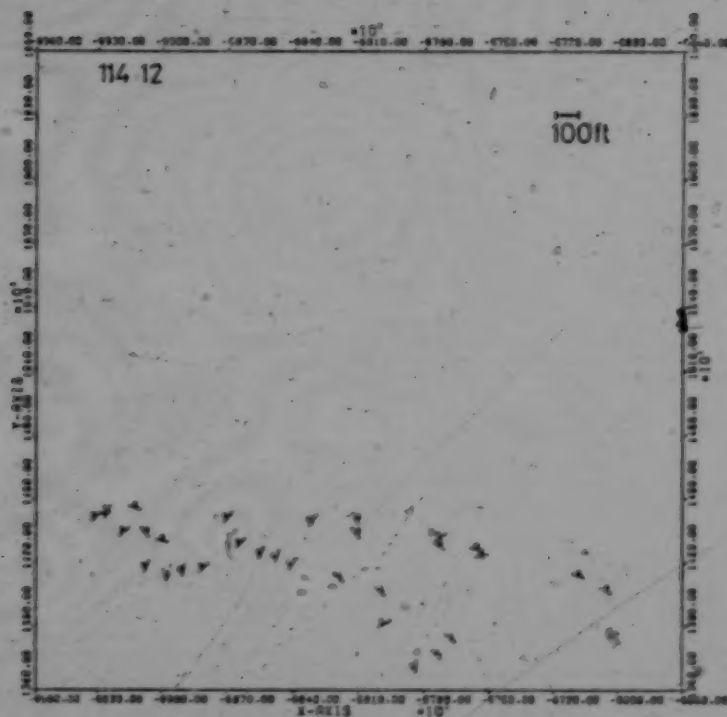
APPENDIX 5-36

DOMAIN - 36



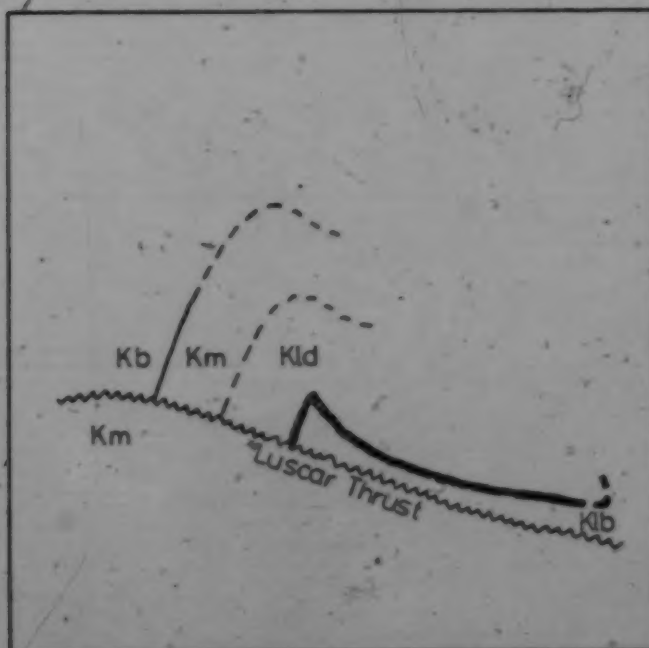
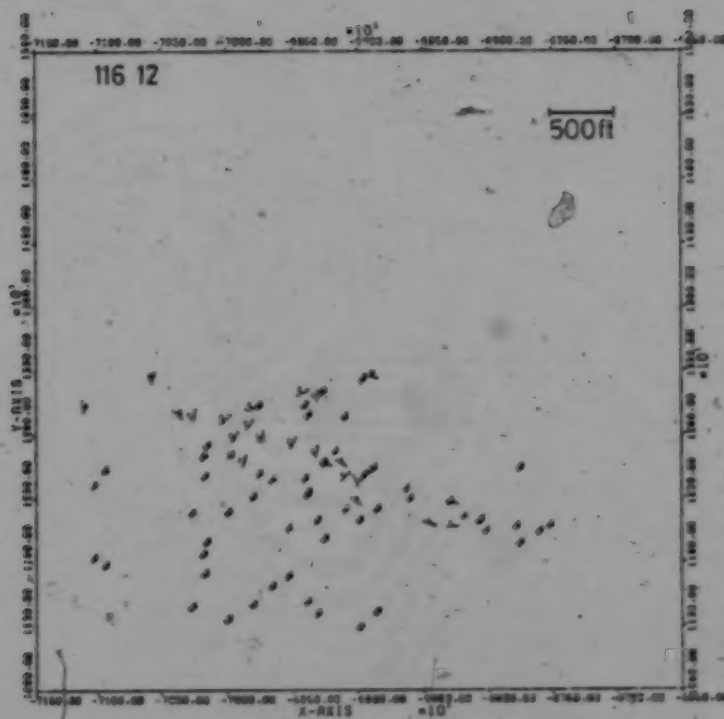
APPENDIX 5-37

DOMAIN 37



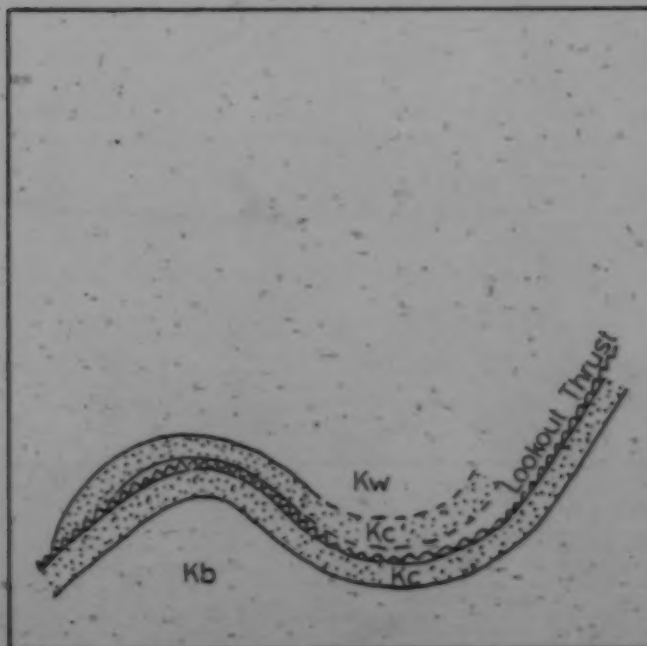
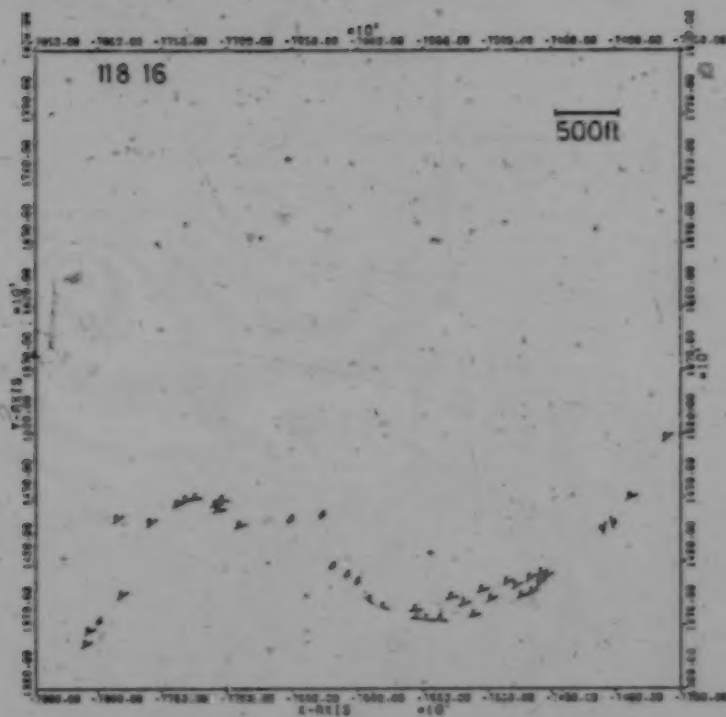
APPENDIX 5-38

DOMAIN 38



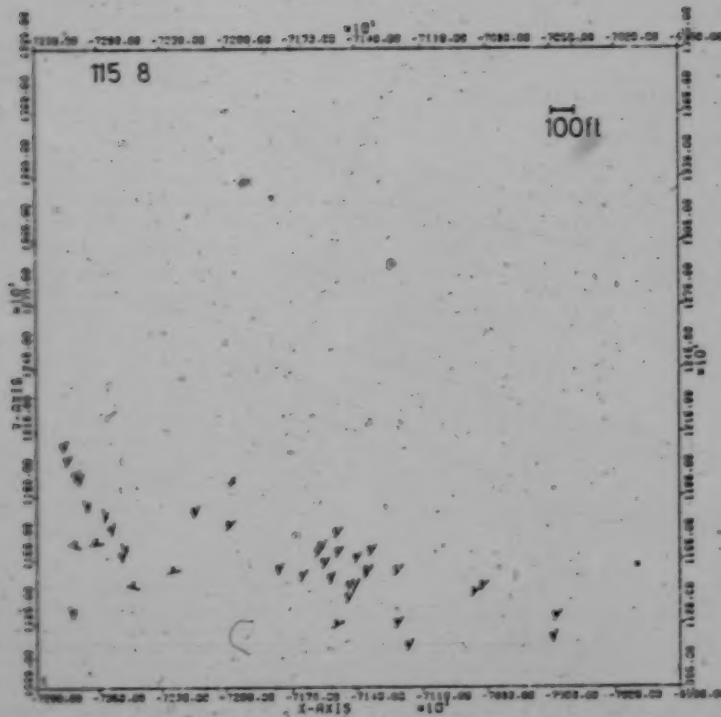
APPENDIX 5-39

DOMAIN 39



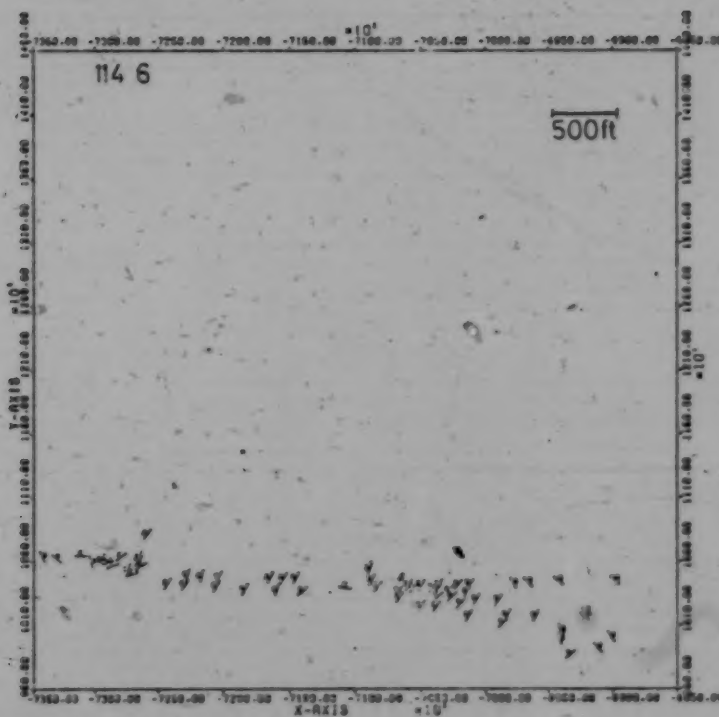
APPENDIX 5-40

DOMAIN 40



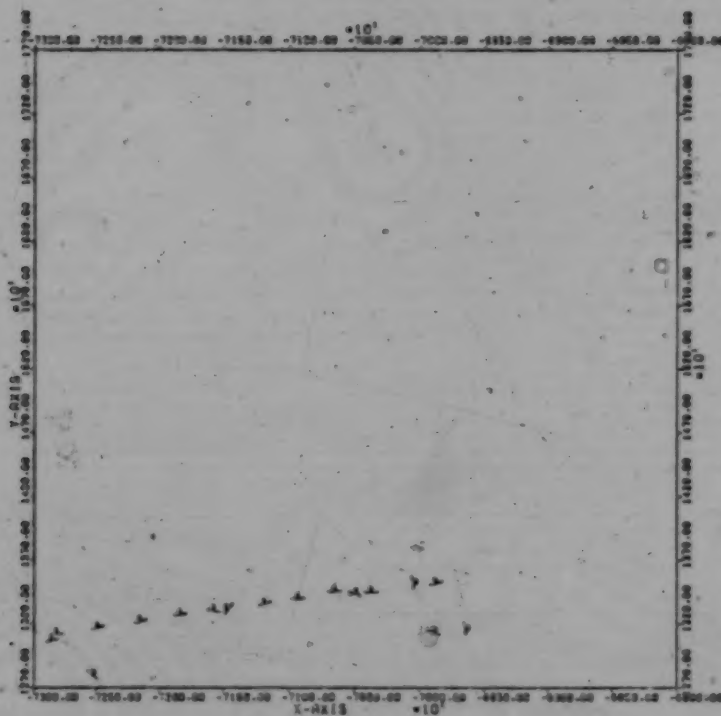
APPENDIX 5-41

DOMAIN 41



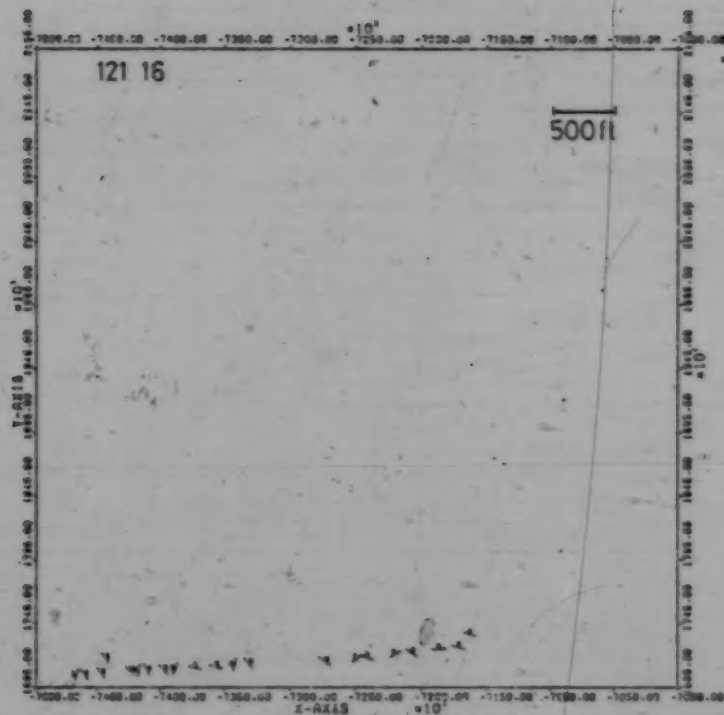
APPENDIX 5-42

DOMAIN 42



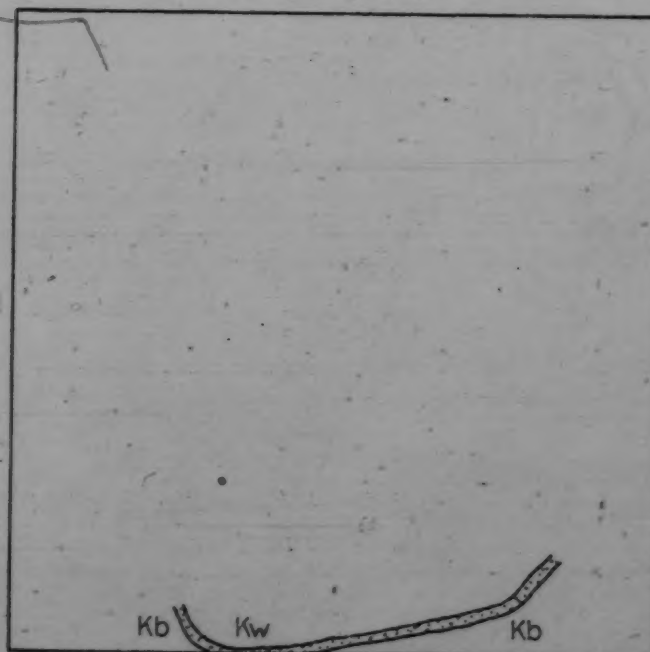
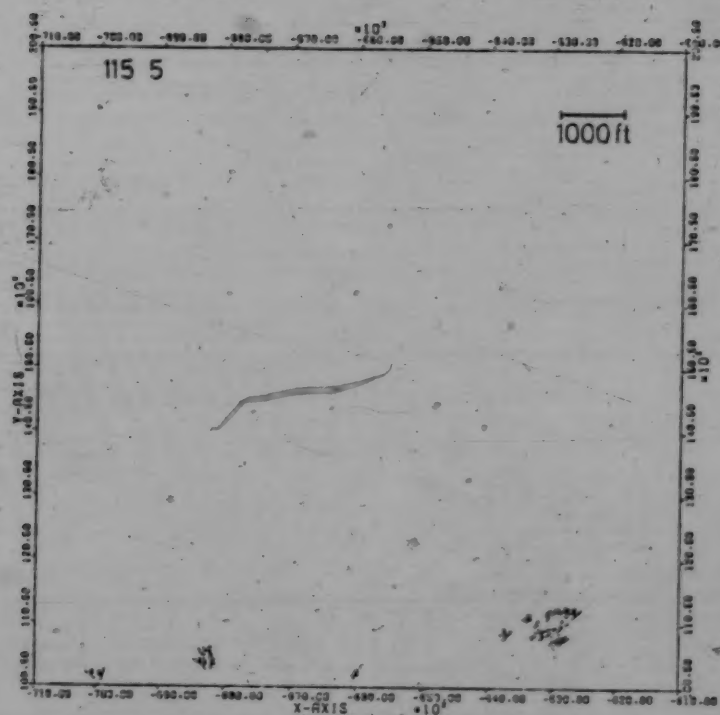
APPENDIX 5-43

DOMAIN 43



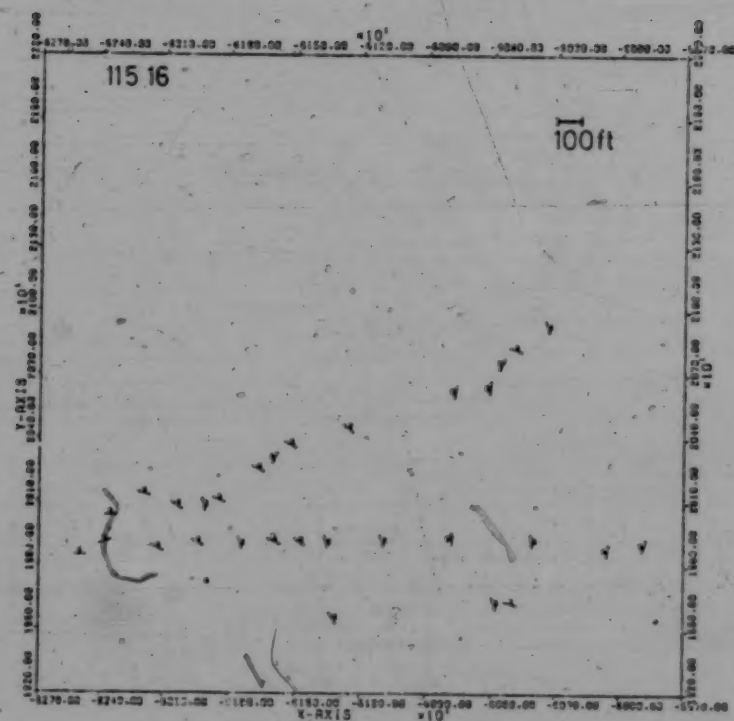
APPENDIX 5-44

DOMAIN 44



APPENDIX 5-45

DOMAIN 45



APPENDIX 6a

Lithologic section through Member D of the Luscar Formation and the basal Mountain Park Formation measured in the 51B2 pit.

m ft -above formation base

39.6 130.0+

Siltstone

30.2 99.0

Fine- to medium-grained, green weathering sandstones showing parallel bedding within large channels up to 50m wide.

23.5 77.0

Highly fissile, black siltstones.

21.6 71.0

Massive, light grey siltstone with some fine-grained sandstone interbeds at the base.

16.8 55.0

Medium-grained, light grey-green, massive, channelled sandstone.

BASE OF MOUNTAIN PARK FORMATION.

421.8 1383.9

TOP OF LUSCAR FORMATION.

Fine-grained, noncalcareous sandstone fining up through fissile sandstone into carbonaceous shale.

420.3 1378.9

Fine-grained, noncalcareous sandstone fining up through fissile siltstone into carbonaceous shale.

418.5 1372.9

Soft, crumbly, carbonaceous shale.

418.0 1371.4

Fine-grained, light grey, slightly calcareous sandstone with plant debris along bedding planes.

416.5 1366.4

Dark grey siltstones gradational into overlying

sandstone.

414.8 1360.9

Fine-grained, light grey, slightly calcareous sandstone.

414.0 1358.4

Dark grey, noncalcareous siltstone with plant remains along bedding planes.

413.1 1355.4

Fine-grained, light grey, brown weathering sandstone containing a 5 cm thick siltstone.

411.9 1351.4

Soft, fissile, dark grey siltstone with coal on top.

411.8 1350.9

Medium-grained, light grey, light green-grey weathering, massive, noncalcareous sandstone with abundant roots in upper 15 cm.

409.5 1343.4

Carbonaceous shale.

409.3 1342.9

Medium-grained, green weathering sandstone fining up to fine-grained sandstone.

407.2 1335.9

Dark grey, orange weathering, fissile siltstone.

405.5 1330.4

Dark green to black, soft, fine siltstone.

404.7 1327.9

Fine-grained, light grey sandstone.

404.1 1325.9

Dark grey-green, soft, highly fissile shale.

403.7 1324.4

Fine-grained sandstone.

402.5 1320.4
Soft siltstone

402.2 1319.4
Fine- to medium-grained, light grey, orange weathering,
noncalcareous sandstone

400.9 1315.4
Dark grey fissile siltstone

399.1 1309.4
Medium-grained, light grey, brown-orange weathering,
noncalcareous sandstone

396.4 1300.4
Shaly coal seam

396.1 1299.4
Shale with 2 thin coal seams

394.1 1292.9
Shaly coal seam

393.9 1292.4
Black shales

391.5 1284.4
Coal seam

391.2 1283.4
Shale passing downward into siltstone with some 15 cm
thick fine-grained sandstones at the base.

388.4 1274.4
Medium-grained, light grey, noncalcareous sandstone with
some coarse grained horizons and thin siltstone bands at
the top. Channelling is well shown by black carbonaceous
horizons.

379.3 1244.4
Coal seam, thins to less than 30 cm elsewhere.

- 378.4 1241.4
Medium-grained, light grey, noncalcareous, crumbly sandstone with abundant roots.
- 376.9 1236.4
Dark grey fissile siltstone.
- 375.9 1233.4
Medium-grained, light grey, mildly calcareous sandstone.
- 372.3 1221.4
Alternating bands of dark grey, sometimes strongly calcareous, fissile siltstone and fine-grained, light grey, orange weathering, noncalcareous sandstone grading into the sandstone below. The bands are 30-90 cm thick at the top, but thinner and dominantly siltstone at the base.
- 355.8 1167.4
Medium- and coarse-grained, light grey, noncalcareous, massive sandstone with 1.5 - 3 m thick horizons packed with fossil wood and plant debris, especially toward the base.
- 332.4 1090.4
Two thin coal seams separated by carbonaceous shale.
- 332.0 1089.4
Dark grey, well-bedded, noncalcareous siltstone passing transitionally into the sandstone below and with 60 cm thick fine-grained sandstone bands at the top.
- 325.3 1067.4
Fine- to medium-grained, light grey, noncalcareous sandstone with abundant fossil wood.
- 320.5 1051.4
Ryder Seam. Very poor, shaly coal.
- 317.1 1040.4
Grey siltstone.
- 315.7 1035.9
Shaly coal.

315.6 1035.4
Dark grey siltstone.

314.1 1030.4
Fine- to medium-grained, noncalcareous sandstone with fossil wood.

311.3 1021.4
Dark grey siltstone.

310.1 1017.4
Fine-grained, orange weathering sandstone gradational with the siltstone below and with a thin, central siltstone parting.

307.7 1009.4
Dark grey, sometimes orange weathering, fissile siltstone.

303.4 995.4
Carbonaceous shale.

303.1 994.4
Dark grey, noncalcareous, fissile siltstone, sometimes grading into fine sandstone.

292.1 958.4
Fine- to medium-grained, light grey, noncalcareous sandstone, but with a central 60 cm thick calcareous band.

288.8 947.4
Dark grey fissile siltstone.

287.2 942.4
Medium-grained, light grey, noncalcareous, well-bedded sandstone with 3-5 cm thick siltstone bands and nodular horizons.

276.6 907.4
Coarse- to medium-grained, light grey, massive sandstone with fossil wood and shale clasts.

267.4 877.4

Dark grey fissile siltstone.

260.7 855.4

Medium- to coarse-grained, light grey, orange weathering, well bedded sandstone.

255.8 839.4

Dark grey siltstone.

254.6 835.4

Jewel seam. Medium vol. bituminous coal with shale partings at 5, 7 and 11 metres from the base.

242.4 795.4

MEMBER C

APPENDIX 6b

Lithologic section measured through Members B and C of the Luscar Formation in the 51C3 pit.

m ft -above formation base

242.4 795.4

MEMBER C

Medium-grained, light grey, buff weathering, noncalcareous, blocky, massive sandstone in upper half, but similar well bedded sandstone in lower half. Plant debris noticeably lacking. Thin chert pebble conglomerates in upper 5 m.

199.8 655.4

TOP OF MEMBER B

Massive, well cemented, slightly calcareous silty sandstone.

198.4 650.9

Dark grey, fissile siltstone with thin sandstone bands.

197.2 646.9

Two alternations of thin, dark grey, fissile siltstone with thick, fine- to medium-grained, orange weathering, non-calcareous sandstone.

196.3 643.9

Fine- to medium-grained, buff weathering, calcareous, massive, but strongly cross bedded sandstone.

191.4 627.9

Dark grey fissile siltstone.

190.7 625.6

Four alternations of siltstone with fine- to medium-grained, orange weathering sandstone.

188.5 618.6

Fine- to medium-grained, orange weathering, noncalcareous sandstone.

188.2 617.3

Siltstone with occasional thin sandstone horizons.

- 185.9 609.8
Orange weathering sandstone with thin interbedded siltstones.
- 185.2 607.6
Dark grey siltstone with thin sandstone bands, gradational into overlying and underlying units.
- 184.4 605.1
Orange weathering sandstone with thin siltstone horizons.
- 182.6 599.1
Dark grey siltstone with few sandstone horizons.
- 180.6 592.6
Dark grey, orange weathering, weakly fissile, massive siltstone.
- 177.3 581.6
Chert pebble conglomerate-gravel with calcite matrix fining up into fine- to medium-grained, calcareous sandstone with many black chert grains and ultimately to silty sandstone.
- 174.2 571.6
Highly fissile shale.
- 173.6 569.6
Thin calcareous sandstone containing calcite and pyrite.
- 173.2 568.3
Black, fissile shales with thin lenticular sandstones.
- 166.2 545.3
Calcareous, resistant siltstone.
- 162.2 532.3
Dark grey siltstones and shales, very poorly exposed.
- 142.4 467.3
Dark grey-black, brown weathering shales containing 5-10 cm thick calcareous coquina horizons and occasional

continuous silty sandstone bands with bivalves on top.
The base of Member B was taken to be at the lowest
fossiliferous band, less than a metre above coal bearing
strata of Member A (Gladstone Formation of McLean).
Fauna include Cardium and Sphaerium.

124.1 407.3

Fine-grained, calcareous sandstone with cemented
bivalves.
BASE OF MEMBER B

124.0 406.8

TOP OF MEMBER A

APPENDIX 6c

Lithologic section measured through Member A of the Luscar Formation along the railway section near Cadomin.

m ft -above formation base

124.0 406.8

TOP OF MEMBER A

Shale and carbonaceous shale at base grading up into dark grey, brown weathering, noncalcareous fissile siltstone with shale showing parallel laminations at the top.

121.4 398.3

Dark grey, orange weathering, calcareous, silty sandstone.

121.3 398.1

Carbonaceous shale bounded by siltstone.

120.9 396.6

Dark grey, buff weathering, calcareous, silty sandstone with 3 thin siltstone partings.

120.0 393.8

Shales grading up into dark grey, mildly calcareous, fissile siltstones.

119.3 391.3

Fine-grained, dark grey, buff weathering sandstone with several very thin siltstone partings, fossil wood and some parallel laminations.

117.6 385.7

Dark grey, fissile siltstone.

117.1 384.3

Fine- to medium-grained, dark grey, buff weathering, noncalcareous sandstone with fine scale cross-beds.

116.8 383.2

Dark grey, brown weathering, fissile siltstone with interbedded shales.

115.2 378.0

Interbedded fine-grained, calcareous sandstone and shale.

114.3 375.0

Coal seam with shale above and below.

113.7 373.0

Fine- to medium-grained, light grey, buff weathering, calcareous sandstone with occasional interbedded siltstone.

112.3 368.5

Thin coal seam in shales.

112.1 367.8

Fine- to medium-grained, light grey, buff weathering, mildly calcareous sandstone with thin shale parting and plant debris, both at the top.

109.9 360.5

Black fissile siltstone.

109.4 359.0

Dark grey, calcareous, fissile, silty sand grading up into fine- to medium-grained, light grey, buff weathering, calcareous sandstone.

106.4 349.0

Light grey-brown weathering, fissile siltstone.

104.1 341.5

Dark grey, mildly calcareous, silty sandstone.

104.0 341.2

Black carbonaceous shale grading up into siltstone.

103.4 339.2

Thin carbonaceous shale grading up into dark grey, green weathering, moderately fissile, sandy siltstone which is massive in the centre.

101.1 331.7

Medium- to fine-grained, light grey, buff weathering,

calcareous sandstone with cross-beds and fossil wood and a 5 cm carbonaceous shale 90 cm above the base.

98.6 323.5

Carbonaceous shale.

98.4 322.8

Dark grey, green weathering siltstones.

97.2 318.8

Fine- to medium-grained, grey, buff weathering, mildly calcareous sandstone with several siltstone partings.

95.6 313.8

Shale with 15 cm carbonaceous shale at top.

94.9 311.3

Green weathering, noncalcareous, moderately fissile, silty sandstone.

94.1 308.7

Fine- to medium-grained, grey, orange weathering, calcareous sandstone.

93.4 306.5

Green-black weathering, fissile siltstone passing into black carbonaceous shale at the top.

91.6 300.5

Medium- to fine-grained, light grey, buff weathering, slightly calcareous sandstone.

91.0 298.7

Black fissile siltstone.

90.7 297.7

Coal and carbonaceous shale.

90.3 296.4

Medium-grained, light grey, buff weathering, noncalcareous sandstone showing fine scale cross-beds.

- 87.3 286.4
Dark grey, light green weathering, mildly calcareous,
fissile silty sandstone.
- 86.7 284.4
Coal grading into carbonaceous shale in the upper 30 cm.
- 85.5 280.4
Medium- to fine-grained, grey, buff weathering,
calcareous, well cross-bedded sandstone.
- 84.9 278.4
Shale containing a 5 cm coal seam.
- 84.6 277.4
Medium- to fine-grained, grey, buff weathering,
calcareous sandstone.
- 84.2 276.4
Shale.
- 83.8 274.9
Coal.
- 83.3 273.3
Green weathering siltstones.
- 82.6 270.9
Medium-grained, grey, buff weathering, weakly calcareous
sandstone containing roots in top 30 cm.
- 80.4 263.9
Shales at base, grading up into fissile siltstone.
- 78.3 256.9
Medium-grained, grey, buff weathering, noncalcareous,
cross-bedded sandstone.
- 77.7 254.9
Two thin coals separated by shale.
- 77.4 253.9

Fine- to medium-grained, grey, buff weathering, mildly calcareous sandstone.

75.6 247.9

Coal and shale passing up into siltstone.

74.6 244.9

Black siltstone/fine sandstone.

73.9 242.4

Shale passing up into siltstone containing 2 carbonaceous shale bands.

72.7 238.4

Medium-grained, reddish-grey, orange weathering, calcareous, massive sandstone;- finer and less massive toward the base.

67.8 222.4

Massive, green weathering siltstone passing up into fissile siltstone overlain by 5 cm coal.

66.4 217.9

Five cm coal overlying 15 cm thick, interbedded, green weathering siltstones and fine calcareous sandstones.

65.7 215.4

Five cm coal overlying green weathering silty shale.

65.0 213.4

Medium-grained, light grey, grey-brown weathering, noncalcareous sandstone.

64.8 212.5

Thin coal overlying shales.

64.5 211.6

Medium- to fine-grained, grey, orange weathering, calcareous sandstone, rhythmically bedded at the base, but cross-bedded at the top and containing roots.

63.7 209.0

Siltstone at base fining up into black shale with 30cm

carbonaceous shale at the top.

61.7 202.5

Fine-grained, light grey, light grey weathering, weakly cemented, massive, noncalcareous sandstone containing roots.

61.2 200.7

Weak, fissile, silty shale.

60.3 197.8

Fine- to medium-grained, light grey, orange weathering, calcareous sandstone with well developed cross-beds and siltstone partings in the basal metre.

57.9 190.1

Green-grey weathering, fissile siltstone.

57.0 187.2

Fine-grained, dark grey, brown weathering, calcareous, silty sandstone with a 7 cm shale parting in the middle.

55.7 182.6

Black shale/fissile siltstone.

55.2 181.1

Fine- to medium-grained, grey, orange weathering, calcareous, well cross-bedded sandstone.

54.0 177.1

Green weathering fissile siltstone.

53.6 175.8

Thin siltstone grading up into medium- to coarse-grained, light grey, grey-brown weathering, noncalcareous sandstone showing both cross beds and ripple lamination.

52.1 170.8

Carbonaceous shale grading up through shale to grey, moderately fissile, fine-grained sandstone and siltstone.

- 51.2 168.1
5 cm carbonaceous shale grading up through 30 cm siltstone to highly nodular and broken up, light grey, orange weathering, calcareous sandstone.
- 49.7 163.1
Fine-grained, grey, mildly calcareous sandstone.
- 49.5 162.4
Brown weathering, fissile siltstone.
- 48.6 159.4
Medium-grained, grey, orange weathering, noncalcareous sandstone containing penetrative roots.
- 48.1 157.9
Black fissile siltstone.
- 46.9 153.9
Thin coal grading up into fine-grained, orange weathering, calcareous sandstone with some interbedded siltstone.
- 45.4 158.9
Fine- to medium-grained, light grey, orange weathering, calcareous, massive sandstone, but cross-bedded on a fine scale.
- 43.9 143.9
Light grey, fissile siltstone.
- 43.6 142.9
Sixty cm coal and shale grading up into black shale.
- 42.8 140.4
Sixty cm medium-grained, light grey, highly calcareous well cross-bedded sandstone fining up into interbedded siltstone and fine-grained sandstone.
- 41.7 136.9
Black shale, often carbonaceous.
- 40.5 132.9

Medium- to fine-grained, light grey, buff weathering, calcareous sandstone with basal siltstone partings.

38.4 125.9

Siltstone fining up into shale.

37.5 122.9

Medium-grained, light grey, buff weathering, calcareous, massive sandstone with a 30 cm shale parting in the middle.

34.9 114.4

Black, carbonaceous shale grading up into green siltstone.

34.4 112.9

Fine-grained, light grey, orange weathering, calcareous sandstone.

34.0 111.6

Shale and carbonaceous shale.

33.8 110.9

Coarse- to medium-grained, light grey, orange weathering, well crossbedded, calcareous sandstone.

32.6 106.9

Silty shale fining up into 5 cm coal.

32.0 104.9

Coarse-grained, well cross-bedded, grey, grey weathering, calcareous sandstone.

31.7 103.9

Grey-green weathering, silty shale.

30.6 100.4

Medium- to coarse-grained, well cross-bedded, red-grey, orange weathering, calcareous sandstone.

30 98.4

Covered.

0 0

Cadomin Formation

APPENDIX 7

Data processing procedures

INPUT	PROCESSING OF FILES	OUTPUT
RAWPLANE	Reformatted and statistics calculated by programs DELET, SORT, MEANS and RESORT	PLANE
RAWFOLD	Reformatted and fold axes calculated by source programs FINPUT and EIGEN	FOLD
SEAM	Processed by SMED to retain only those holes that intersect Jewel seam	SEAM2 or SEAM3
HOLE and SEAM2 or SEAM3	Processed by CONVERT to change co-ordinates from mine grid to map grid and calculate co-ordinates of coal intersections	COLLARS CARDINAL2 CARDINAL3
CARDINAL2 CARDINAL3	Processed by CAR2DIT or CAR3DIT to retain upper or lower intersections, respectively	JEWEL2 or JEWEL3
HOLE and JEWEL2	Processed by FIND to retain only those holes that do not intersect Jewel seam	HOLES
HOLES	Processed by CON to calculate the co-ordinates of top and bottom of hole	NOCOAL NOCOALB

APPENDIX 8

Statistics used to test cylindricity.

Fcalc.....Calculated value of F statistic

D. of F.....Degrees of freedom

Chi calc....Calculated value of chi-squared statistic

Max eval....Maximum eigenvalue

Int eval....Intermediate eigenvalue

Min eval....Minimum eigenvalue

Scat ang....Scatter angle

PART 1

Domain	Fcalc	D. of F.	Chi calc	D. of F.
1	3.00	2, 17	11.28	19
2	0.44	2, 13	25.00	15
4	0.46	2, 67	166.97	69
5	2.73	2, 16	20.45	18
6	0.92	2, 24	25.41	26
7	2.26	2, 34	46.60	36
8	0.79	2, 16	39.72	18
9	3.31	2, 21	24.89	23
10	0.34	2, 18	48.10	20
11	1.54	2, 33	49.43	35
12	2.22	2, 14	37.38	16
15	1.41	2, 6	23.03	8
23	2.31	2, 7	4.97	9
24	2.45	2, 22	63.42	24
26	0.61	2, 44	87.84	46
27	0.47	2, 16	88.90	18
28	0.10	2, 16	71.98	18
33	0.52	2, 15	50.32	17
35	0.72	2, 9	25.73	11
36	0.42	2, 15	18.90	17

PART 1 (continued)

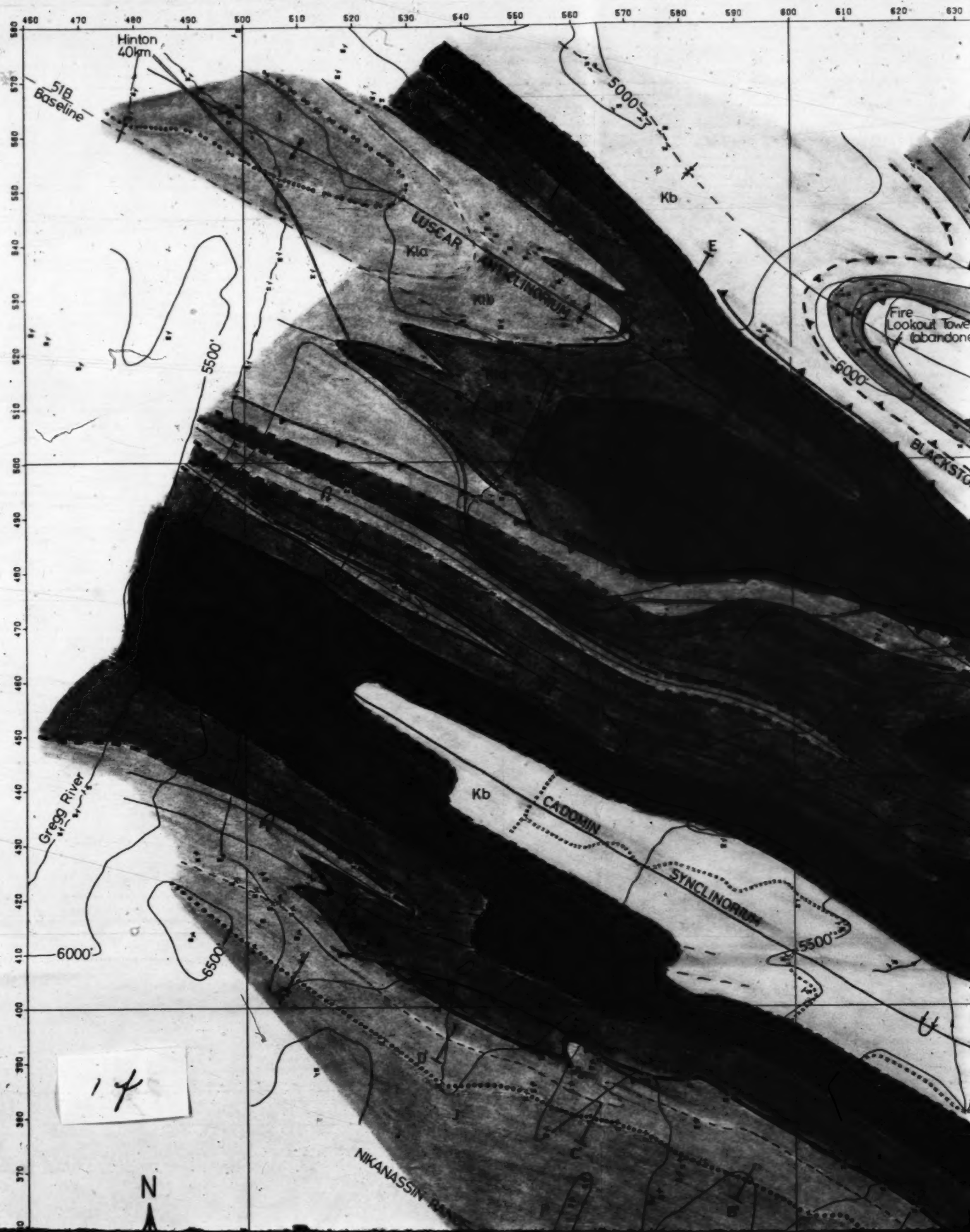
Domain	Fcalc	D. of F.	Chi calc	D. of F.
37	0.39	2,25	143.51	27
38	0.18	2,19	70.83	21
39	2.02	2,31	74.96	33
40	2.77	2,33	55.05	35
41	2.53	2,60	91.71	62
44	0.35	2,32	79.49	34
45	2.23	2,26	93.39	28

PART 2

DOMAIN	MAX EVAL	INT EVAL	MIN EVAL	SCAT ANG
1	18.6510	2.2899	0.0590	3.2
2	14.8327	2.1047	0.0625	3.7
3	14.2144	2.5158	0.2698	7.7
4	61.6072	8.4119	0.9802	6.8
5	12.2901	7.6489	0.0609	3.3
6	24.8773	2.9325	0.1901	4.9
7	29.9800	7.1122	0.9076	9.1
8	13.7956	5.8159	0.3884	8.4
9	22.9486	1.9411	0.1102	4.0
10	18.2741	3.3907	0.3351	7.4
11	33.3191	3.3191	0.3616	5.8
12	15.4909	2.2599	0.2491	7.2
13	10.6540	1.2309	0.1150	6.2
14	10.1958	1.0912	0.7129	15.5
15	9.1377	0.6304	0.2320	9.8
19	7.0274	0.9536	0.0190	3.2
20	14.4129	6.1892	0.3979	8.3
21	6.5090	1.3686	0.1223	8.2
22	3.9947	1.8320	0.1733	12.0
23	8.4012	2.4768	0.1219	6.7

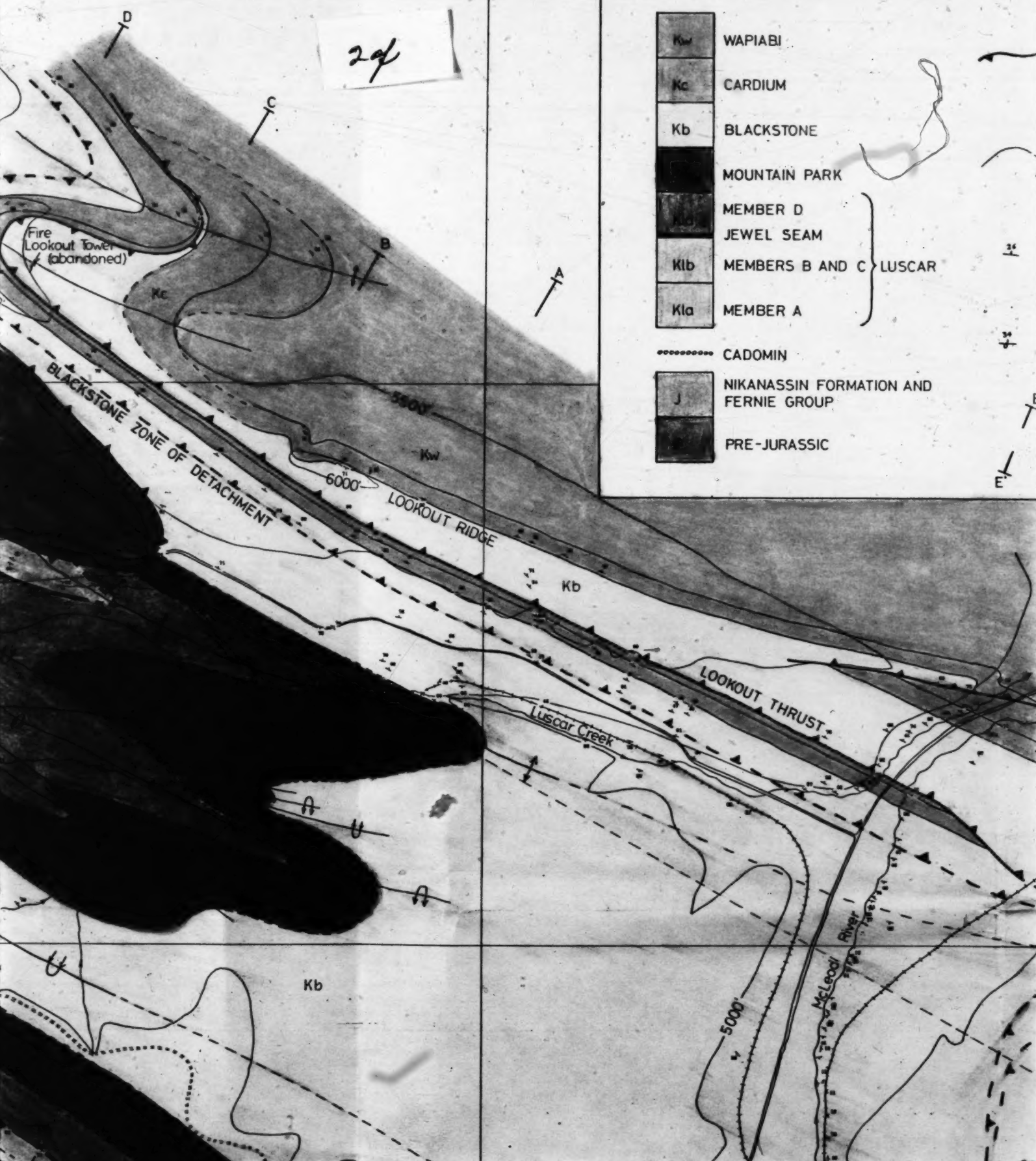
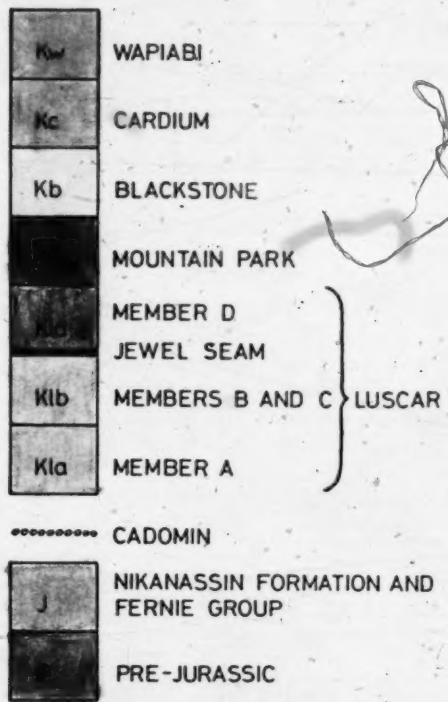
PART 2 (continued)

DOMAIN	MAX EVAL	INT EVAL	MIN EVAL	SCAT ANG
24	22.8170	2.9455	0.2375	5.7
26	32.2987	15.1900	0.5110	6.1
27	13.2083	5.9242	0.8674	12.7
28	12.5611	7.1625	0.2763	7.1
29	5.5438	0.4353	0.0208	4.1
30	12.2130	0.7618	0.0252	2.7
31	7.2978	0.6522	0.0500	5.2
33	11.8297	6.9218	0.2484	6.9
34	6.4898	5.3530	0.1572	7.2
35	8.5196	4.2995	0.1808	7.4
36	12.4297	6.2911	0.2792	7.4
37	15.3383	12.7633	0.8984	10.5
38	12.6946	9.8625	0.4428	8.3
39	30.3419	4.2607	0.3971	6.3
40	30.7745	5.8266	0.3987	6.1
41	48.9854	14.3113	0.7028	6.1
42	13.1110	3.6113	0.2776	7.8
43	13.9841	6.8539	0.1620	5.3
44	27.8601	7.7271	0.4126	6.3
45	19.6655	9.7644	0.5700	8.2



620 630 640 650 660 670 680 690 700 710 720 730 740 750 760 770 780 790

29



730 740 750 760 770 780 790 800 810 820 830 840 850 860 870 880 890 900

LEGEND



WAPIABI

CARDIUM

BLACKSTONE

MOUNTAIN PARK

MEMBER D

JEWEL SEAM

MEMBERS B AND C

MEMBER A

CADOMIN

NIKANASSIN FORMATION AND
FERNIE GROUP

PRE-JURASSIC

THRUST FAULT
(Teeth on hanging wall)

LITHOLOGIC BOUNDARY
(Broken where uncertain)

BEDDING ORIENTATION

OVERTURNED BEDDING

CROSS-SECTION LOCATION

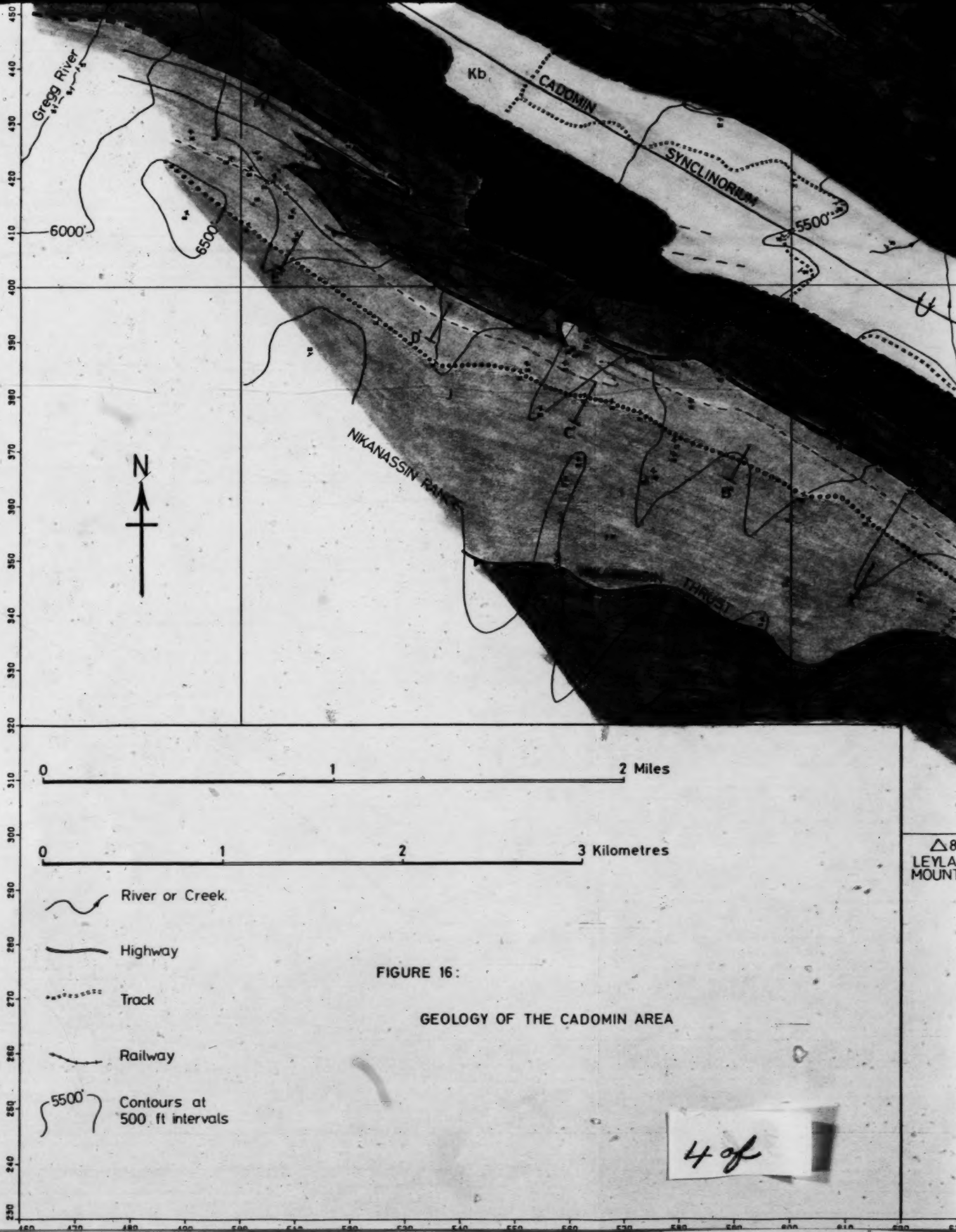
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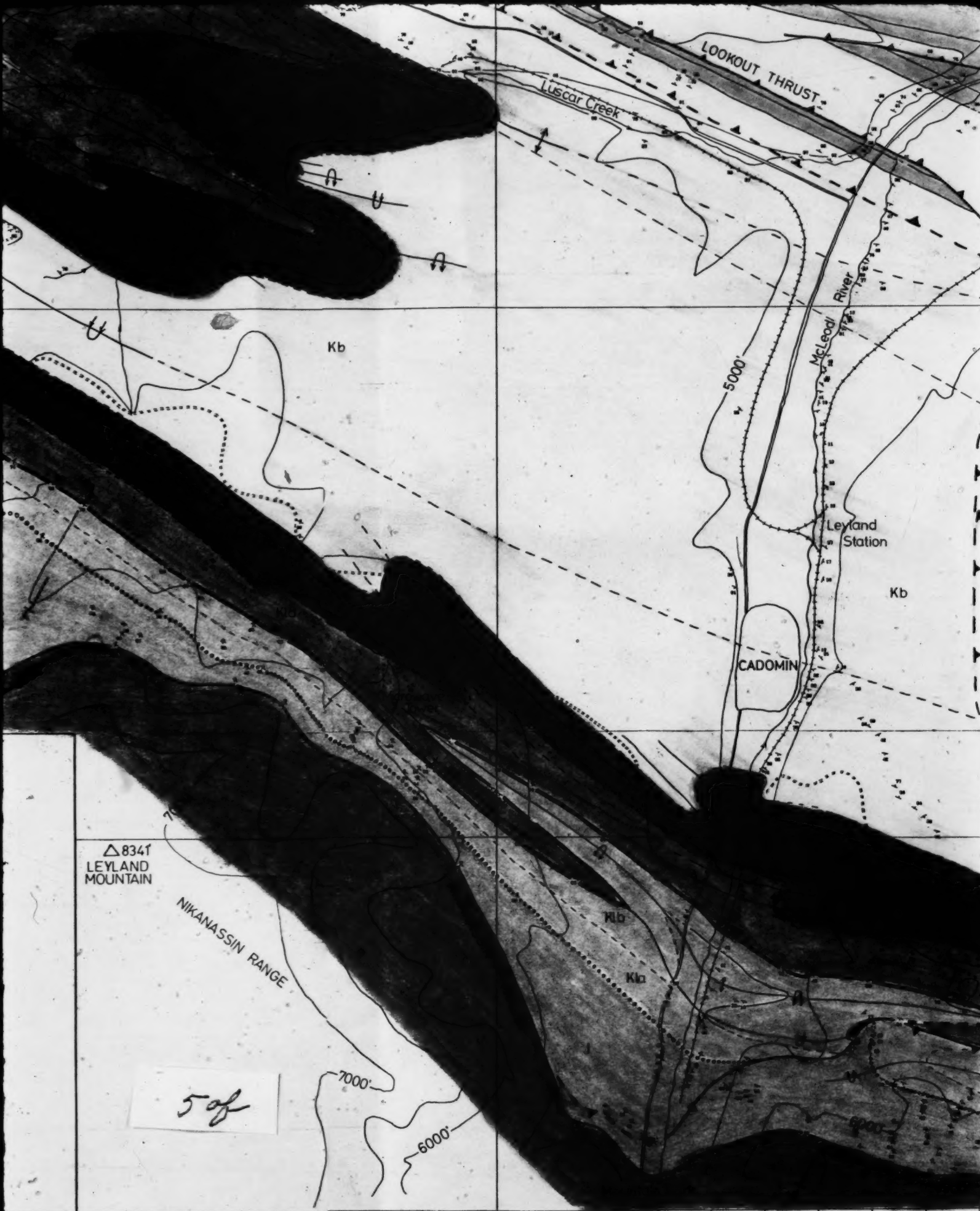
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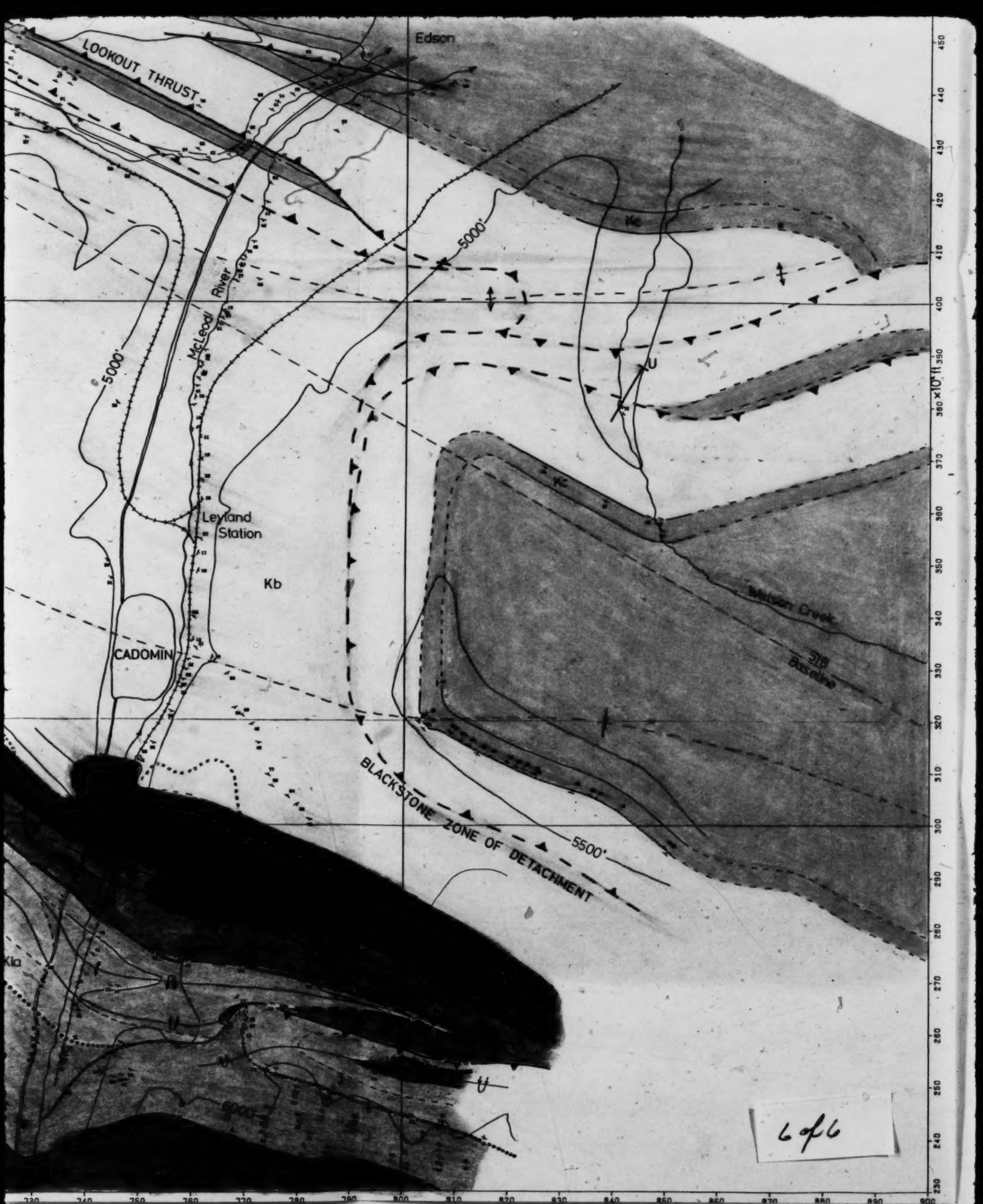
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OVERTURNED SYNCLINE



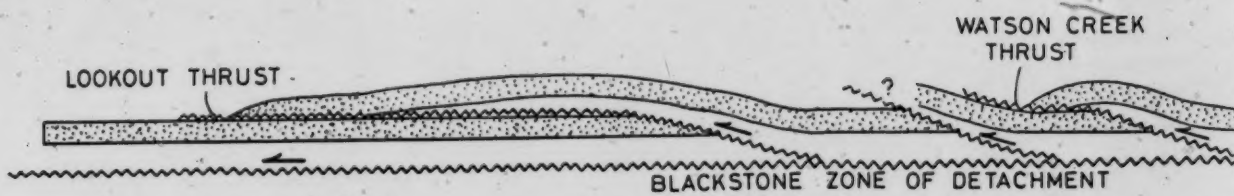






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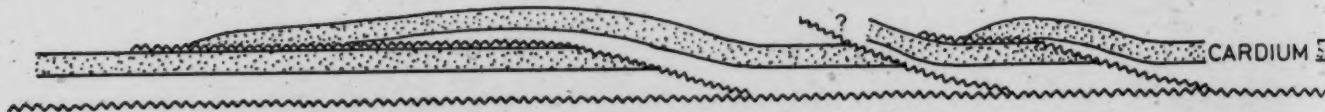
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TOP OF MOUNTAIN PARK FORMATION

BASE OF MOOSEBAR SHALES

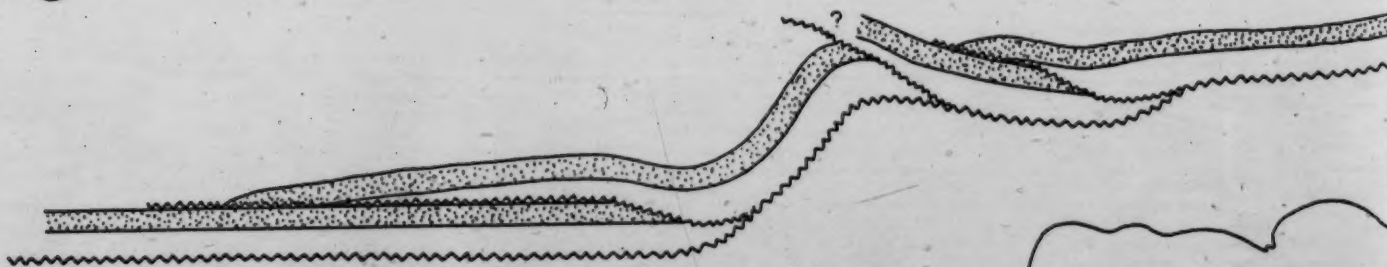
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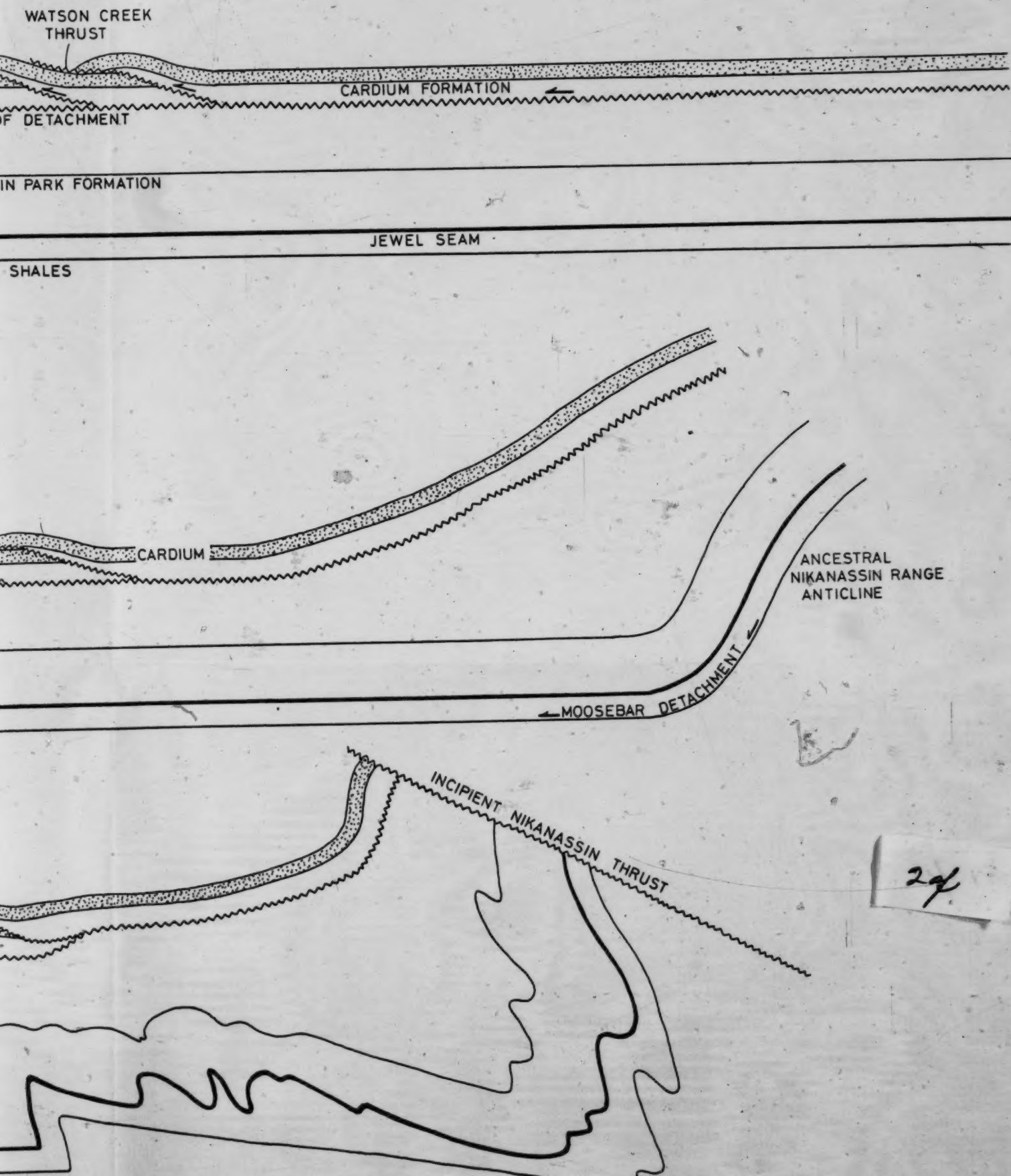
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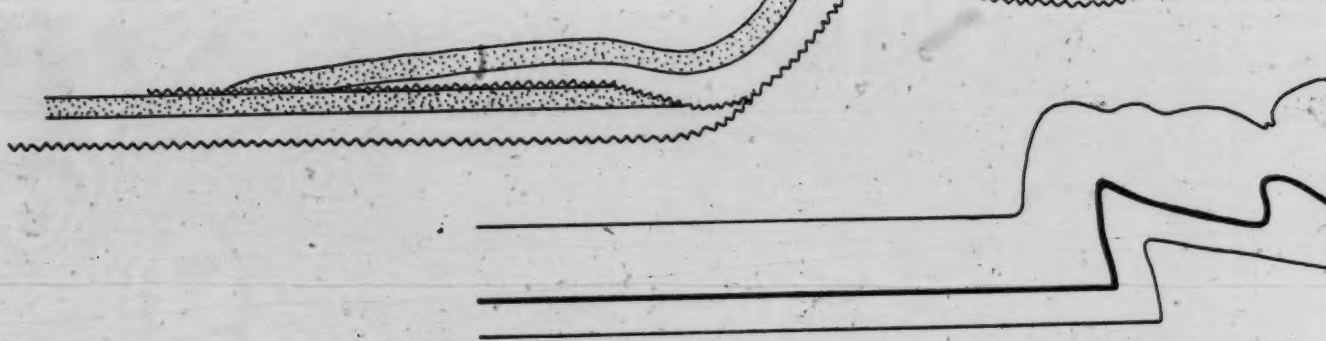
JEWEL SEAM

c

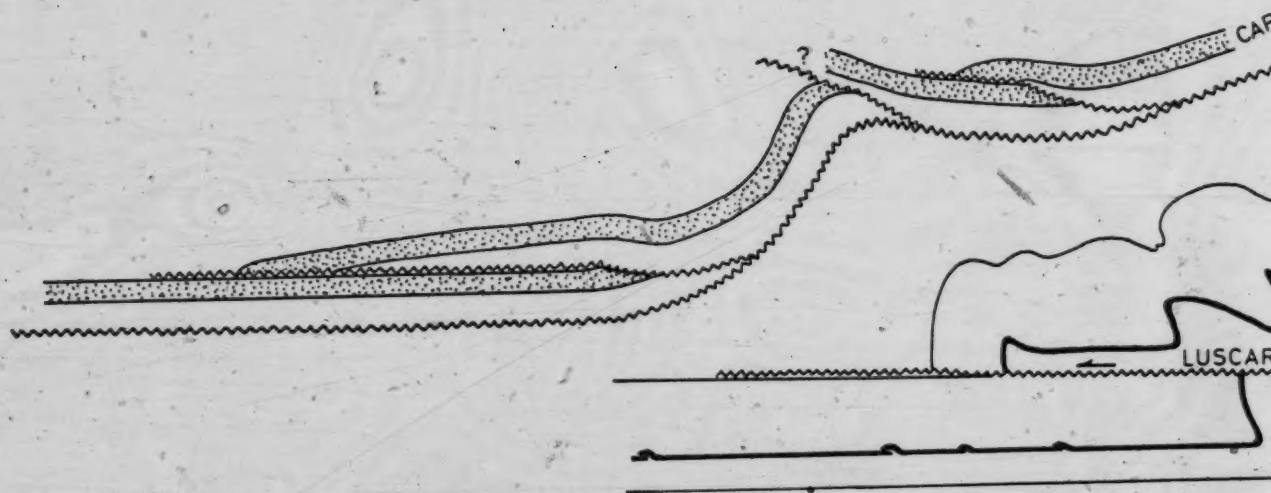


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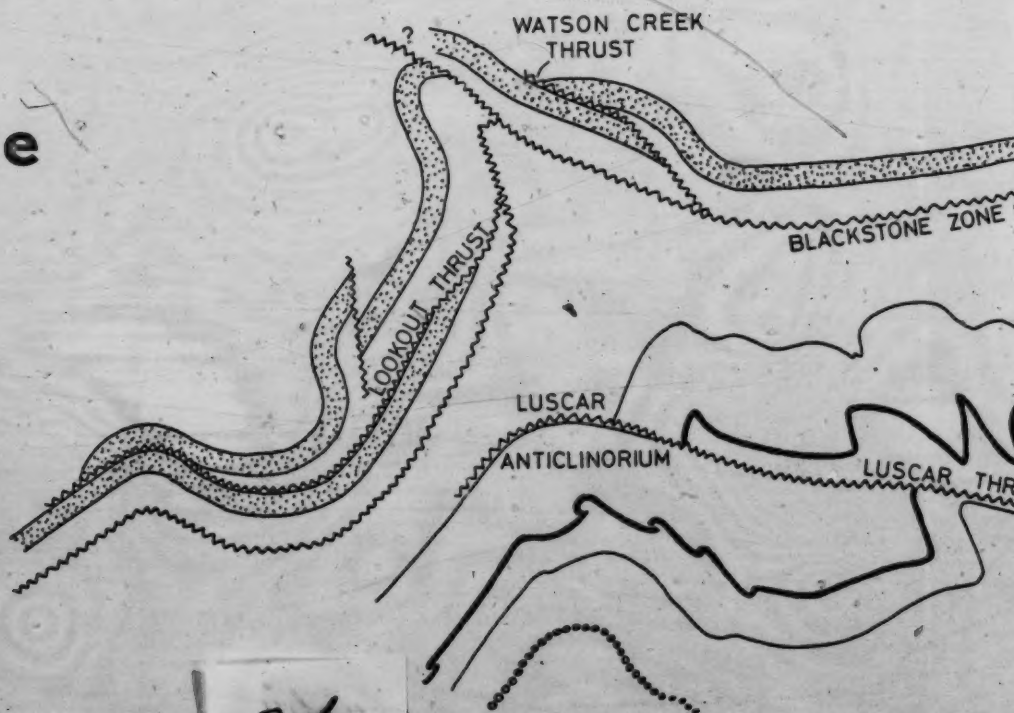




d



e

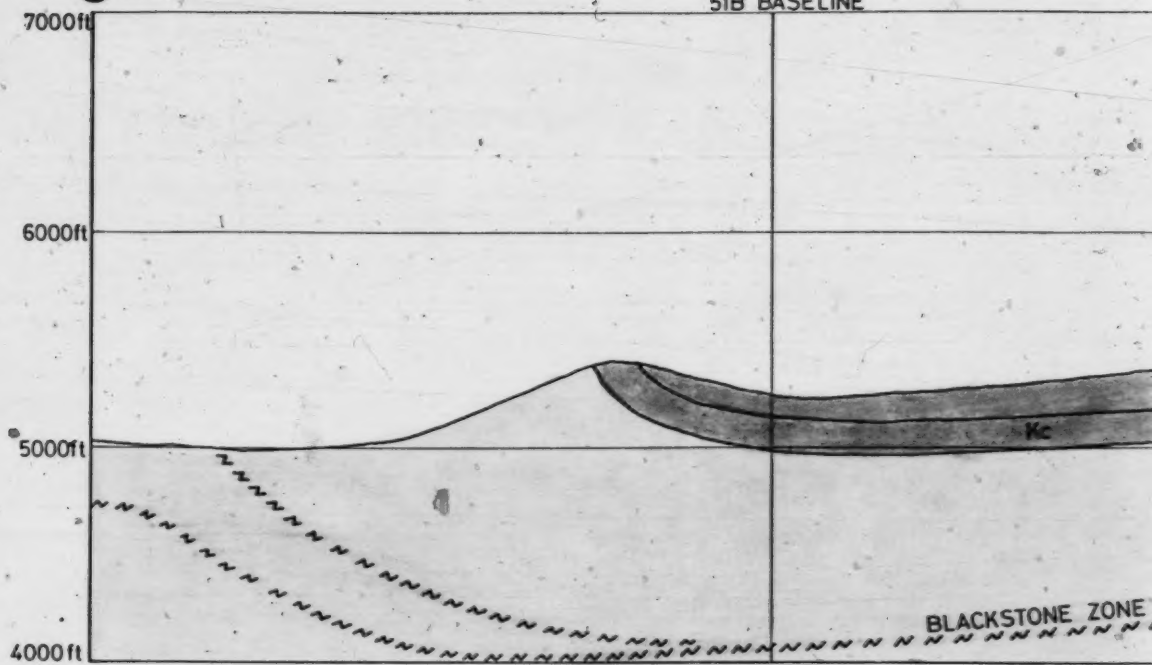




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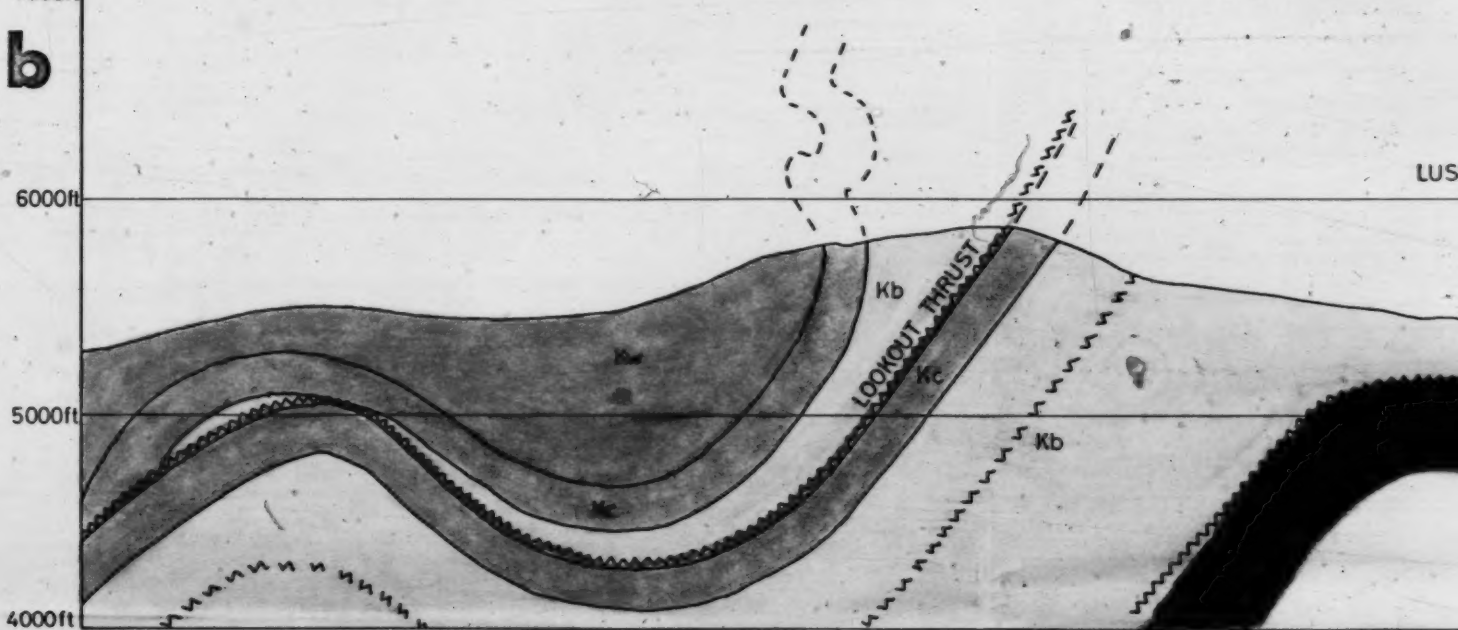
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51B BASELINE



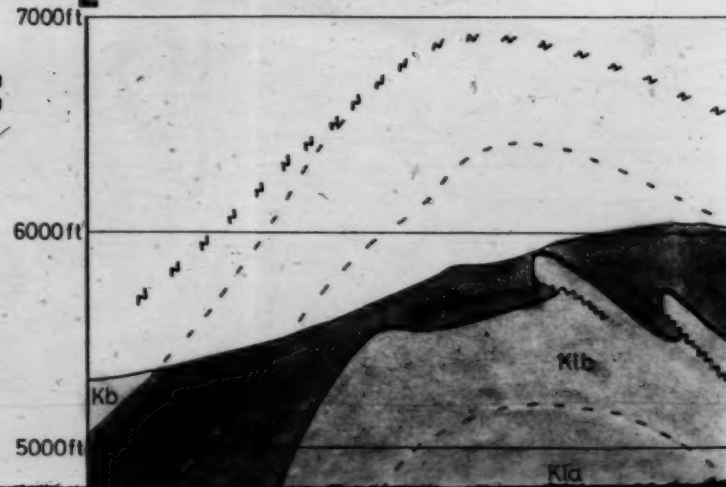
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b

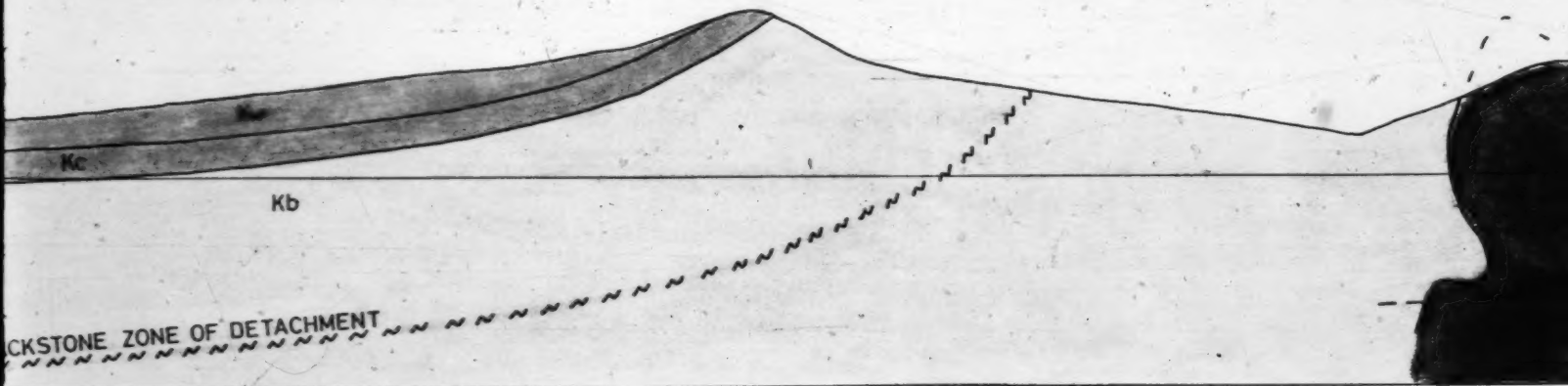


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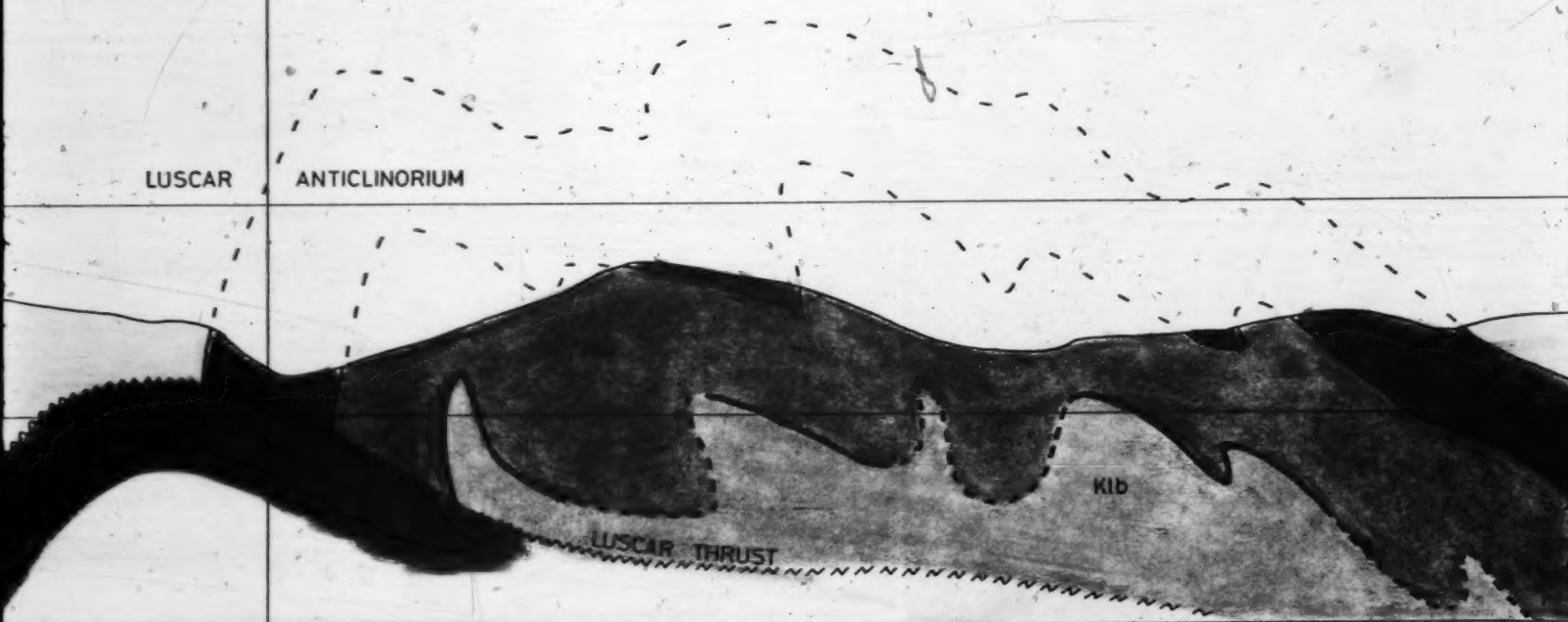
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51B BASELINE

LUSCAR

ANTICLINORIUM



51B BASELINE

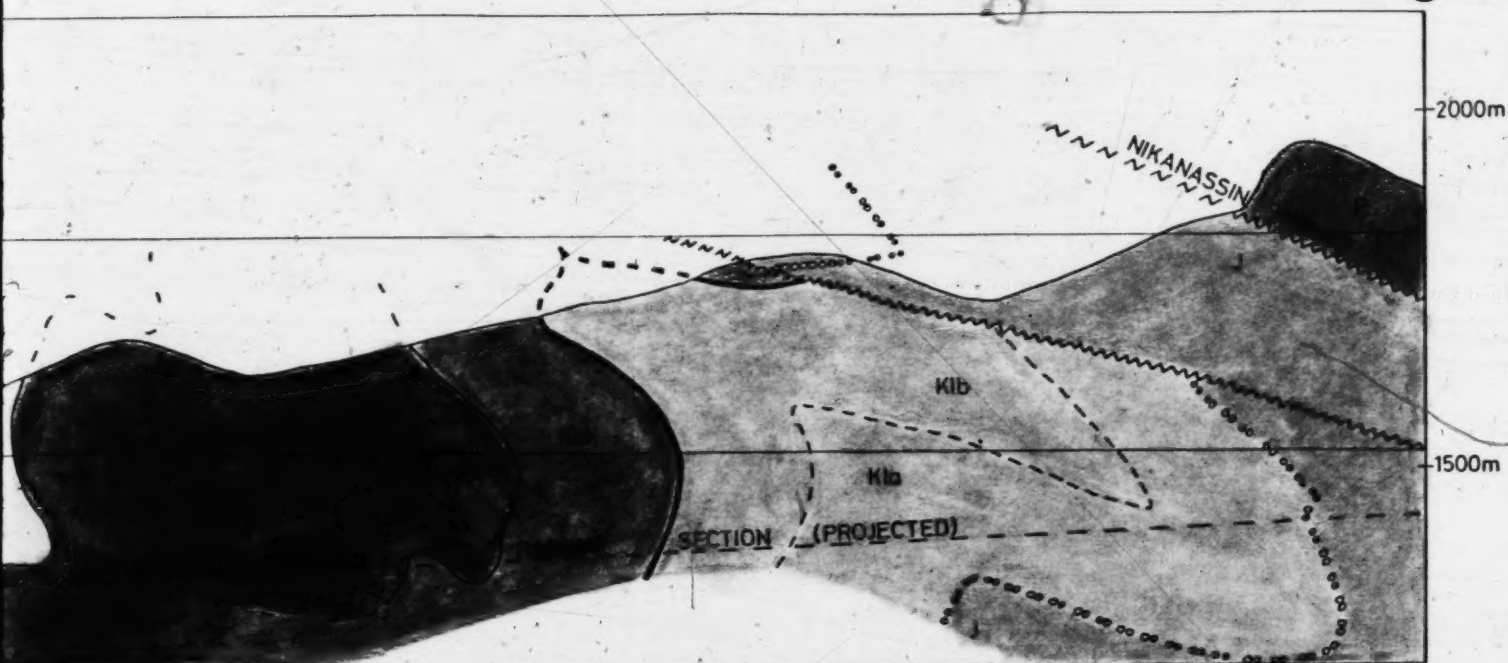
Klb

LUSCAR THRUST



SW

U'



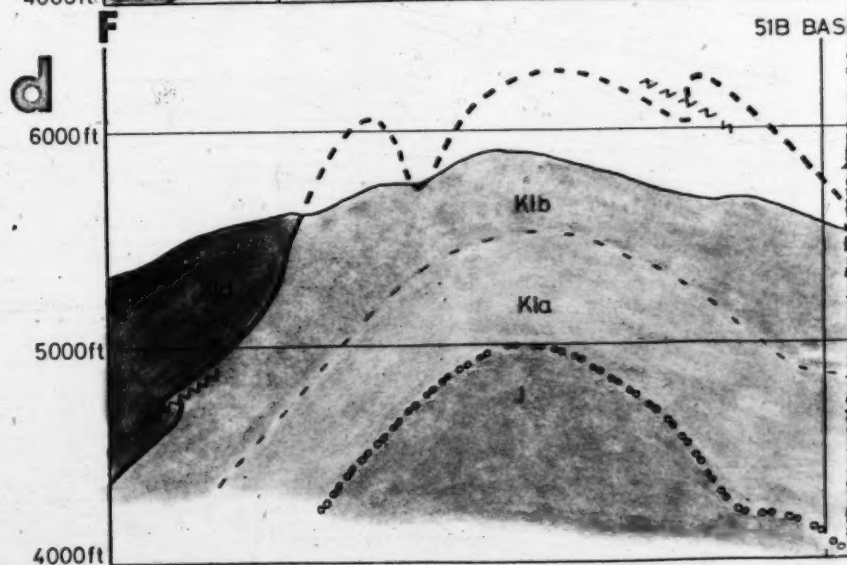
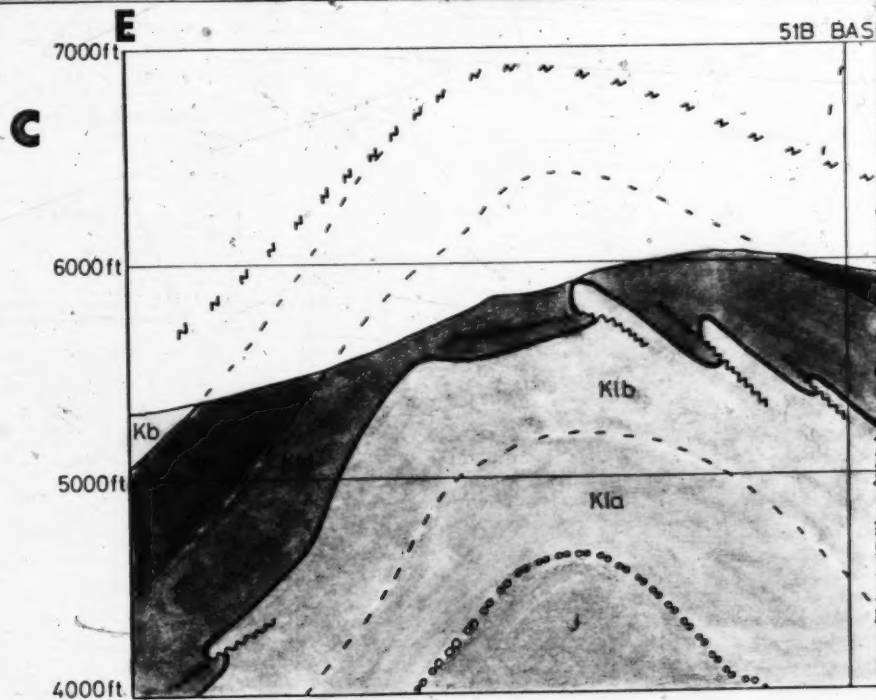
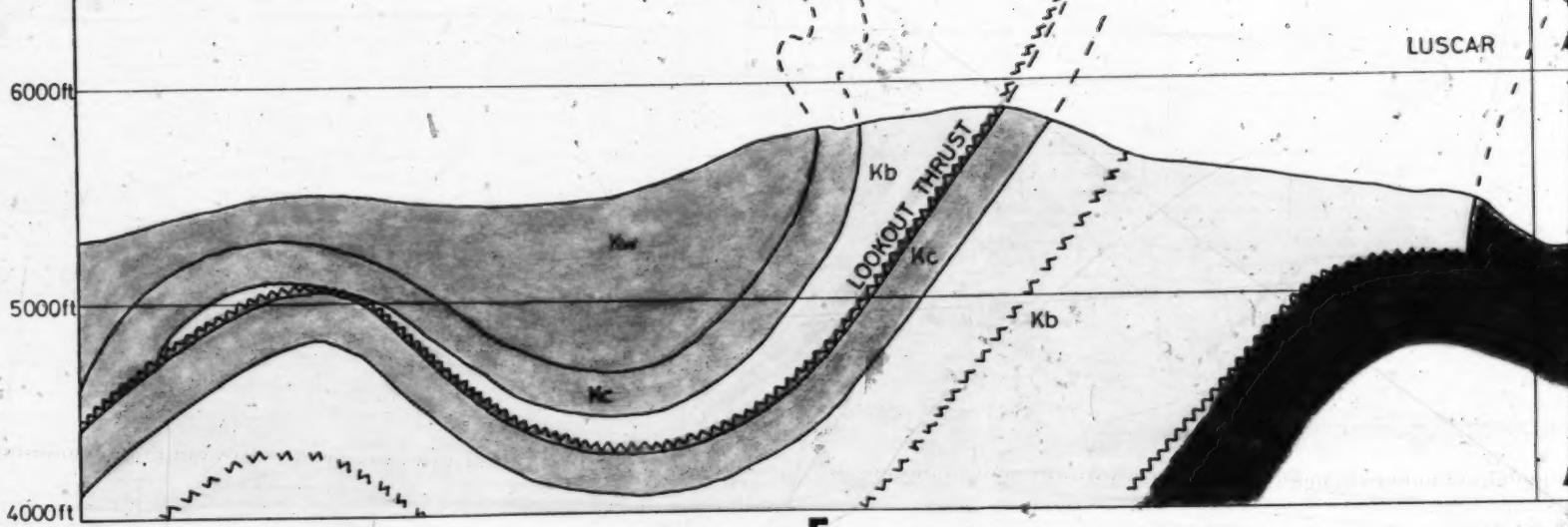
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3 of

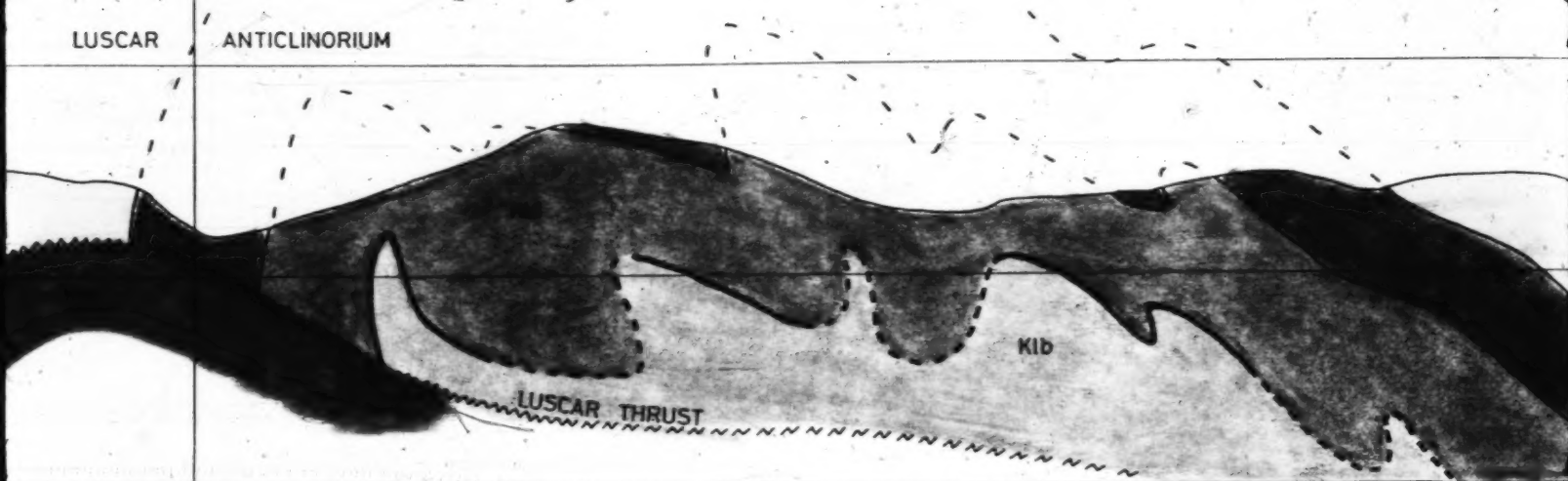
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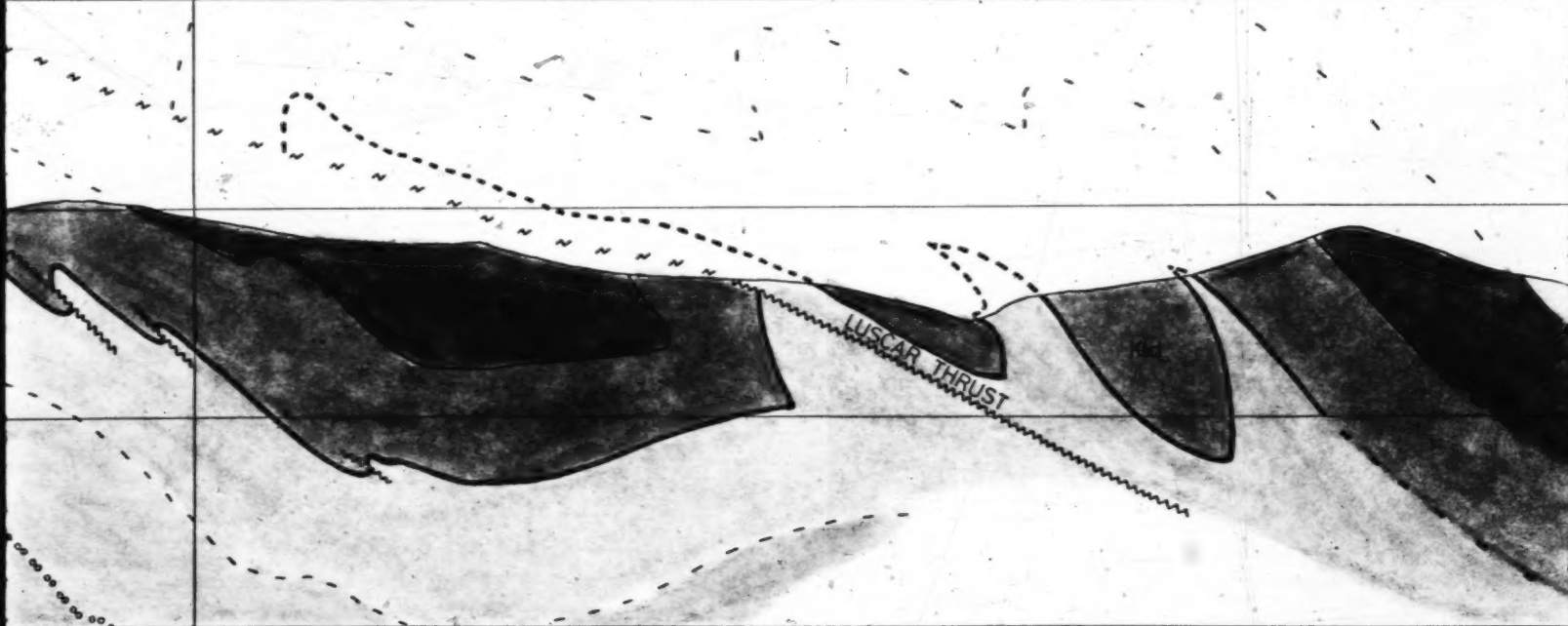


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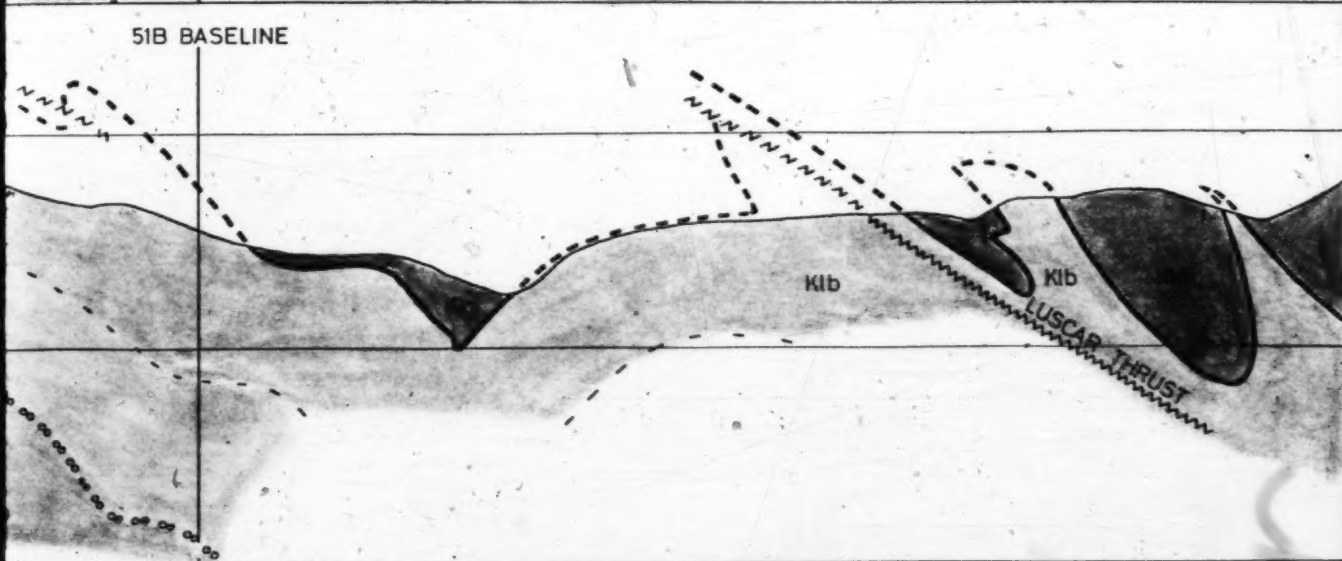
ANTICLINORIUM



51B BASELINE



51B BASELINE



F

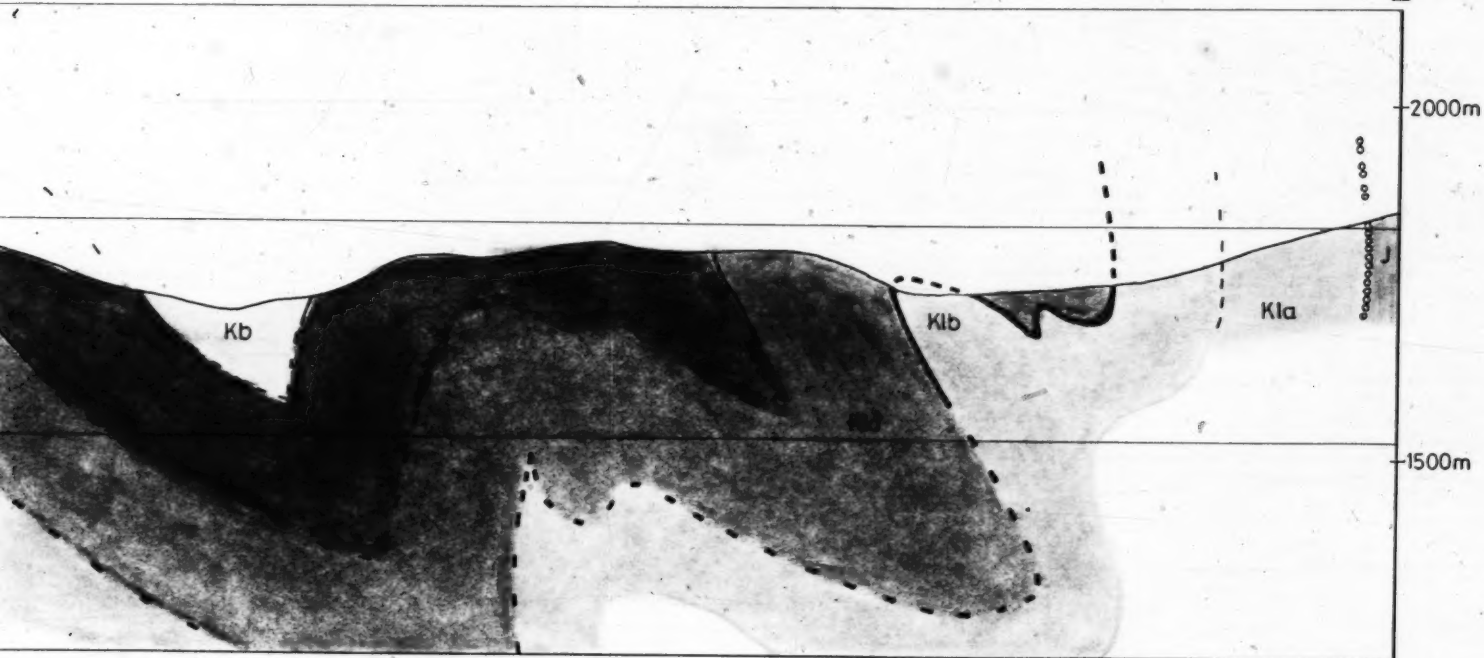
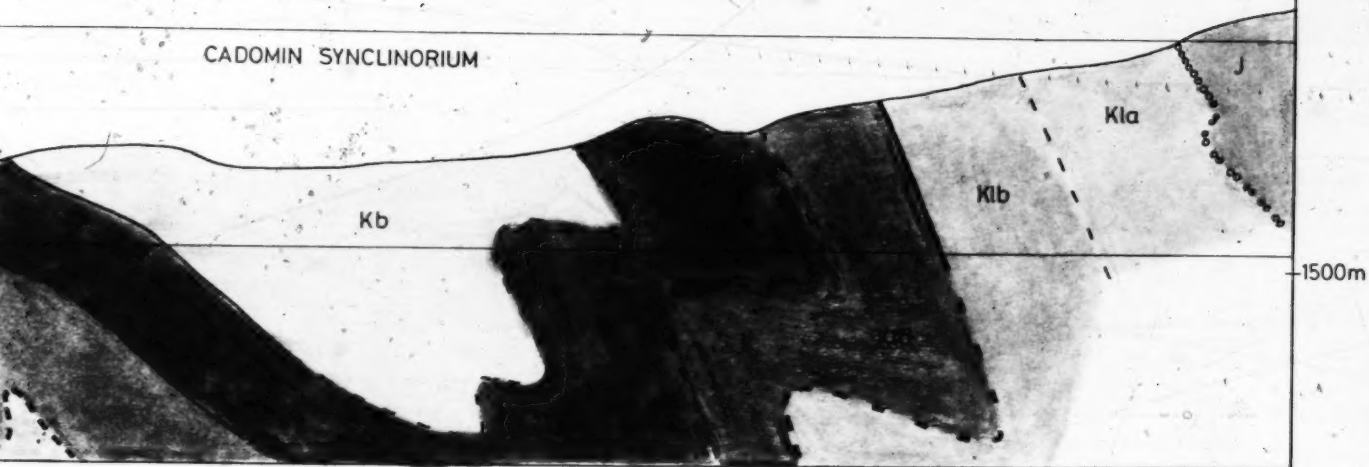
NATURAL

SEE FIG

SEE FIG

1500m

5 of



NATURAL SCALE

1 MILE

1 KILOMETRE

~~~~~ THRUST FAULT

SEE FIG 16 FOR LEGEND

FIGURE 17: CROSS-SECTIONS U-U', B-B', E-E' AND F-F'.

6 of 6